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THE PHYSICAL AND CHEMICAL CHARACTER OF NEW JERSEY GREENSAND.[1]

GEORGE ROGERS MANSFIELD.

INTRODUCTION.

Shortly before the armistice in 1918 the U. S. Geological Survey in cooperation with the New Jersey Department of Conservation and Development undertook an investigation of the potash resources of the New Jersey greensand marl beds, as a part of the general investigation of sources of potash in the United States. The primary object was to secure data on the thickness, character, quality, and amount of the marl at places favorably situated for commercial enterprise and to determine the amount and character of the overburden at those places.

In all 19 holes were sunk, ranging in depth from 9 to 70 feet and averaging 37 feet. A fairly complete series of continuous samples of the greensand marl was obtained from these holes, 12 of which afforded complete sections from the surface through the marl beds. The stratigraphic data obtained have been summarized in a previous paper in this *Journal*.[2] In the present paper the results of mechanical and chemical analyses of selected samples are discussed. A detailed report on the entire investiga-

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Mansfield, G. R., "General Features of the New Jersey Glauconite Beds," ECONOMIC GEOLOGY, Vol. 14, No. 7, pp. 555–567, Nov., 1919.

tion has been prepared for publication as a bulletin of the U. S. Geological Survey.

MECHANICAL ANALYSES OF GREENSAND.

Nature of Investigation.—Variations observed in the character of the material at the different borings made it necessary to study the constituents of the marl in relation to their possible bearing on commercial operations. There was hope also that this study might throw some additional light on the origin and nature of glauconite. Mechanical analyses, following in a general way the work of Cook[3] and Ashley,[4] were accordingly undertaken both to separate the marl into its respective constituents and to secure material for chemical analysis and microscopic study. The mechanical analyses included: (1) wet separation of unaltered greensand; (2) magnetic separation of the coarser residues from (1); and (3) sizing the products of (2). The operations and results are summarized below.

Preparation of Samples.—Composite samples, 15 in all, derived from 87 originals, were prepared to represent each bed of commercial thickness at each of the 6 localities explored. Each sample weighed approximately 100 grams and was made up of weighed portions of all samples taken from the given bed at the given locality, each in proportion to the thickness represented by it. The material was weighed without preliminary drying, but at the end check samples weighing 100 grams each were dried under the same conditions to which the composite samples were subjected, and reweighed to determine the loss of moisture in drying.

Wet Separation.—After preliminary trials, in which it was found that cloudy, colloidal matter continued to be yielded by the greensand upon agitation in water long after the finer sedimentary material had been washed out, the following procedure was observed. The weighed sample, placed in a beaker, was a little

[3] Cook, G. H., "Geology of New Jersey," pp. 277–280, 1868.

[4] Ashley, G. H., "Notes on the Greensand Deposits of the United States," U. S. Geol. Survey Bull. 660, p. 30, 1918.

more than covered with distilled water. The greensand was then stirred vigorously with a rod for one minute and allowed to settle for 30 seconds, after which the cloudy liquid was decanted into a second beaker. These operations were repeated to a total of 10 times for the first 5 samples and 15 times for the remaining 10 samples. The washed greensand was then removed to a casserole, dried on a steam bath, and weighed. A few drops of dialyzed iron were added to the cloudy liquid which was then allowed to settle, after which the clear water was decanted and the settlings dried and weighed in the same manner. In samples G–2, 10, 13, 14, and 15 the entire washing waters were dried without flocculation and precipitation by dialyzed iron. The results are given in Table I.

TABLE I.

WET SEPARATIONS OF COMPOSITE SAMPLES OF GREENSAND FROM SURVEY BORINGS AT SALEM, WOODSTOWN, SEWELL, SOMERDALE, ELMWOOD ROAD, AND PEMBERTON, N. J.

Locality.	Sample No.	Approximate Thickness of Bed.	Residue *A*.	Fines *B*.
		Feet.	Per cent.	Per cent.
Salem	G– 1	12	95.6	4.5
	G– 2	11	97.3	2.7
Woodstown	G– 3	11	79.3	20.7
	G– 4	11	85.7	14.3
	G– 5	7	88.8	11.2
Sewell	G– 6	8	53.4	46.6
	G– 7	12	81.5	18.5
	G– 8	13	86.2	13.9
Somerdale	G– 9	8	40.0	60.0
	G–10	6	52.4	47.6
	G–11	14	71.2	28.8
Elmwood Road	G–12	4	88.3	11.8
	G–13	18	97.3	2.7
	G–14	23	84.3	15.6
Pemberton	G–15	9	76.8	23.2
Averages[5]			80.5	19.5

At Sewell three types of marl are recognized commercially, namely, gray or bank marl at the top, green marl, and chocolate marl. These subdivisions with some variations may be recog-

[5] Averages weighted according to the thickness of the respective beds.

nized throughout a considerable area and correspond in a general way with the grouping of the beds in the table. The upper two beds at each locality correspond probably with the Middle marl of Cook or the Hornerstown marl, according to present nomenclature; and the lowest bed with the Lower marl of Cook, now called the Navesink. The bed at Pemberton, however, is the Upper marl of Cook, now known as the Manasquan.

The percentage of fines in the greensand at the 6 localities named ranges from 2.7 to 60 and averages 19.5.

Magnetic Separation.—Glauconite is moderately magnetic and may be separated from quartz and other non-magnetic substances by passing the dried greensand through a strongly magnetic field. The residues listed in the preceding table were presented successively in small quantities close under a glass plate placed against the poles of a powerful electro-magnet. The glauconite was attracted and held to the glass plate so long as the plate was in contact with the poles of the magnet. By lowering the plate the glauconite could be dropped into any convenient receptacle. This action was repeated until no further results could be secured and thus fairly complete separations were obtained.

As tabulated below the numbers of the samples and the beds represented are the same as for the wet separations. Ten-gram portions of each sample were used and the products of the separations were weighed.

The percentage of magnetic materials, chiefly glauconite, in the washed greensand is generally high, being more than 90 in 10 of the 15 samples and averaging 89.9 for all the beds represented. The percentage of glauconite grains in the unmodified greensand is shown for each bed at each locality in the last column of the table. The final average shows 73 per cent. of glauconite for the entire thickness of the marl examined at each of the six localities. This figure does not include the finely divided glauconitic material occurring in the greensand as mud or "clay" (*B*) in the previous table. No mechanical separation of the fines or mud was attempted but chemical analyses indicate that it is probably highly glauconitic.

Size of Grains.—Both products of the magnetic separation (*C*) and (*D*) of the following table were passed successively through a series of sieves having respectively, 20, 40, 60, 80, and 100 meshes to the inch. The grains held on each sieve and in the receiver below the lowest sieve were weighed and the percentage of each product was determined. The tabulation is too long to repeat in this paper.

TABLE II.

MAGNETIC SEPARATION OF SAMPLES OF WASHED GREENSAND FROM SALEM, WOODSTOWN, SEWELL, SOMERDALE, ELMWOOD ROAD, AND PEMBERTON, N. J.

Locality	Sample No.	Magnetic Portion (C) Chiefly Glauconite.	Non-magnetic Portion (D) Chiefly Quartz.	Glauconite Grains in Original Sample CxA (Table I).
		Per cent.	Per cent.	Per cent.
Salem	G– 1A	87.3	12.7	83.5
	G– 2A	94.1	5.9	91.6
Woodstown	G– 3A	80.4	19.6	63.8
	G– 4A	96.0	3.9	82.2
	G– 5A	92.5	7.5	82.1
Sewell	G– 6A	82.3	17.7	43.9
	G– 7A	97.0	3.0	79.1
	G– 8A	94.5	5.5	81.5
Somerdale	G– 9A	92.6	7.4	37.0
	G–10A	96.6	3.4	50.6
	G–11A	96.0	4.0	68.4
Elmwood Road	G–12A	62.5	37.5	55.2
	G–13A	94.5	5.5	91.9
	G–14A	96.0	4.0	80.9
Pemberton	G–15A	52.4	47.6	40.2
Averages[6]		89.9	10.1	73.1

The glauconite particles range in diameter from more than one twentieth to less than one hundredth of an inch, but the greatest number by weight fall between one twentieth and one fortieth of an inch, though many fall between one fortieth and one sixtieth of an inch. Below the last size the number of glauconite grains falls off rapidly, though a few samples, especially G–9A, have considerable material of the smaller sizes.

The quartz grains, too, fall chiefly between one twentieth and one sixtieth of an inch, but there is a large percentage also of the finest grains.

[6] Averages weighted according to thicknesses of beds represented.

Shapes of Grains.—The largest sized glauconite grains, one twentieth of an inch or more in diameter, show their form most clearly. Under the hand lens they appear irregular, botryoidal, or mammillary in general form, suggesting aggregates of rounded grains, rather than casts of foraminiferal shells, though some grains suggest such form. Many appear to be rounded nodules with irregular cracks of lighter color. The grains in general have a shiny surface and dark green color. The one fortieth and one sixtieth sizes show similar form and markings but a greater degree of regularity as if reduced by wear from larger size. Some of the grains are elongate or curved and have a platy structure or cleavage. The smaller sizes are subangular to rounded, though retaining to some extent the suggestion of earlier form and markings. They have evidently been much worn and represent, at least in part, material that has been transported and redeposited. Other grains have seed-like or capsule form and range in diameter from one fortieth of an inch downward. These, tested qualitatively, give a strong reaction for phosphate. Typical glauconite grains, somewhat magnified, are shown in Plate XVIII.

The quartz grains are generally irregular, angular, or subangular, though some of the larger sized grains (one fortieth to one twentieth of an inch) are rounded.

CHEMICAL ANALYSES OF GREENSAND.

Composition of Greensand.—Numerous analyses of greensand samples from different parts of New Jersey are given by Cook.[7] Much time, however, has elapsed since the publication of that work and there have been changes in methods. For example, it does not appear that in the analyses given by Cook the Na_2O was separately determined. Further, as pointed out by Hicks and Bailey,[8] the methods employed at that time would normally give results too low in potash. Four complete analyses

[7] Cook, G. H., "The Geology of New Jersey," pp. 417–441, 1868.

[8] Hicks, W. B., and Bailey, R. K., "Methods of Analysis of Greensand," U S. Geol. Survey Bull. 660, p. 52, 1918.

of greensand were therefore made in the present investigation. These are given in Table III.

TABLE III.

ANALYSES OF GREENSAND FROM PEMBERTON, ELMWOOD ROAD, SEWELL, AND WOODSTOWN, N. J.

Analyst—R. K. Bailey.

	M-119.	M-99.	M-52.	M-15.
SiO_2	68.90	50.74	51.83	50.32
Fe_2O_3	8.91	17.36	17.15	18.38
FeO	1.52	3.34	2.93	3.02
Al_2O_3	3.52	1.93	6.23	7.53
CaO	2.10	2.86	0.52	0.65
MgO	1.90	3.76	3.66	3.82
K_2O	3.56	6.68	6.60	7.88
Na_2O	0.82	1.53	0.76	0.22
CO_2	1.00	0.88	0.36	0.15
P_2O_5	1.05	1.79	0.31	0.34
H_2O	7.68	9.08	9.98	8.58
	100.96	99.95	100.42	100.89

M–119 is Manasquan marl from the property of Norcross and Edmunds about three quarters of a mile west of South Pemberton station in Burlington County.

M–99 is Hornerstown marl from the farm of Alphonso Fusco at Elmwood Road station in Burlington County.

M–52 is Hornerstown marl from the property of the West Jersey Marl and Transportation Co. about half a mile southeast of Sewell station in Gloucester County.

M–15 is Hornerstown marl from the field of Isaac K. Lippincott at the north edge of the borough of Woodstown in Salem County.

Silica constitutes about 50 per cent. of the greensand of the Hornerstown marl but nearly 70 per cent. of the Manasquan sample. The last is probably due to the greater admixture of quartz grains in the marl.

All the samples show a relatively high content of ferric iron.

The potash content of the Hornerstown samples is about double that of the Manasquan.

The percentages of CaO, P_2O_5, and CO_2 indicate that only

small quantities of the carbonate and phosphate of lime are present in the better grade greensand marls. Some of the P_2O_5 is doubtless combined with iron instead of with lime, for the mineral vivianite occurs at a number of the localities sampled.

Some of the iron is probably present in the form of sulphides or sulphates as indicated by the sulphuric acid of many of Cook's analyses and by the occurrence at some places of pyrite or marcasite grains or nodules. The water from the marl is locally sulphuretted or irony.

Composition of Products of Wet Separation.—In order to compare the composition of the residues with that of the fines complete analyses were made of two representative pairs of samples resulting from the wet separation, see Table I. These are given in Table IV.

TABLE IV.

COMPOSITION OF PRODUCTS OF WET SEPARATION.

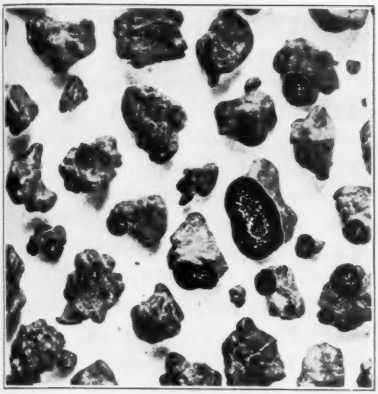
Analyst—R. K. Bailey.

Sample No.	G-7A.	G-7B.	G-13A.	G-13B.
Product.	Coarse Residue.	Fine Washings.	Coarse Residue.	Fine Washings.
Locality.	Sewell.	Sewell.	Elmwood Road.	Elmwood Road.
SiO_2	50.38	49.30	49.50	43.70
Fe_2O_3	18.69	16.33	18.27	15.50
FeO	2.84	2.61	3.03	2.54
Al_2O_3	7.83	8.92	6.52	11.10
CaO	0.37	0.72	1.77	3.43
MgO	3.54	3.44	3.78	2.99
K_2O	7.85	6.74	7.37	5.73
Na_2O	0.30	0.36	0.26	1.15
CO_2	0.10	2.48	0.30	4.04
P_2O_5	0.28	0.64	1.09	[9]
H_2O	8.70	9.22	8.98	10.80
	100.88	100.76	100.87	100.98

These analyses appear to justify the view that the fine or clay-like constituents of the greensand marl have practically the same composition as the coarser constituents and that much of the fine material is finely comminuted or amorphous glauconite. When these samples are compared with each other or with samples

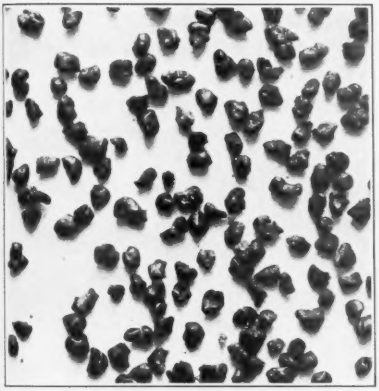
[9] No material left for P_2O_5 determination.

PLATE XVIII.

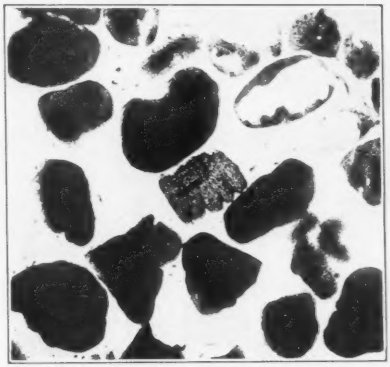


a

b



c



d

Microphotographs of glauconite:

a. Grains between 1/10 and 1/20 inch diameter, the maximum size, showing characteristic shapes (× 9).

b. Grains between 1/20 and 1/40 inch; shapes similar to *a*, but more worn (× 9).

c. Grains between 1/40 and 1/60 inch; shapes similar to *a* and *b*, but much more worn (× 9).

d. Thin section of glauconite grains between 1/40 and 1/60 inch, showing flaky to granular structure of glauconite. In the center is a supposed crystal with rude cleavage (× 36).

M–99, M–522, and M–15 of Table III. certain variations appear, but the quantities of the respective constituents are of the same order.

Potash Content of the Fines.—The potash content of the fines of the washed samples was determined because of its possible bearing on the treatment of the marl in commercial operations. If the fines should prove decidedly lower in potash than either the coarser residues or the unaltered marl it might pay to wash the marl before extracting the potash. In general, the fines contained from 3 to 7 per cent. of potash or from 0.1 to 1.5 per cent. less potash than the unaltered marl. Since the fines average 19.5 per cent. of the marl at the localities examined, see Table I., concentration by washing would undoubtedly increase the proportion of potash in the resulting residues. This gain would be offset by a resulting loss of potash in the fines so nearly equal that the expense of washing would not be justified.

Composition of Glauconite.—Cayeux[10] cites a group of analyses showing the chemical composition of actual glauconite. The samples in the given set are all of recent material mostly taken by the Challenger expedition. The analyses are presented in the following table.

TABLE V.

CHEMICAL COMPOSITION OF RECENT GLAUCONITE.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	56.62	50.85	51.80	55.17	27.74	46.90	47.46
Al_2O_3	12.54	8.92	8.67	8.12	13.02	4.06	1.53
Fe_2O_3.....	15.63	24.40	24.21	21.59	39.93	27.09	30.83
FeO	1.18	1.66	1.54	1.95	1.76	3.60	3.10
CaO.....	1.69	1.26	1.27	1.34	1.19	0.20	—
MgO	2.49	3.13	3.04	2.83	4.62	0.70	2.41
K_2O	2.52	4.21	3.86	3.36	0.95	6.16	7.76
Na_2O	0.90	0.25	0.25	0.27	0.62	1.28	—
H_2O	6.84	5.55	5.68	5.76	10.85	9.25	7.00
	100.41	100.23	100.32	100.39	100.68	99.24	100.09

Analyses 1–5 are from the Challenger reports.

[10] Cayeux, Lucien, "Introduction à l'étude pétrographique des roches sedimentaires," Memoirs pour servir à l'explication de la carte géologique detailée de la France, pp. 242–244, Paris, 1916.

No. 6 is from the Agulhas Bank, Indian Ocean (Gümbel, C. W., K-bayer, Akad. Wiss. Sitzungsb., vol. 16, p. 417, 1886).

No. 7 is material from the Challenger office, described by L. W. Collet ("Les Dépôts Marins," Encyclopédie Scientifique, p. 167, Paris, 1908) as "the purest specimen of actual glauconite which has ever been found."

The noteworthy features of these analyses are the relatively high percentage of ferric iron as compared with ferrous iron, the relatively high alumina content, and the low or moderate potash content.

Cayeux[11] also cites a list of 23 analyses of glauconite from older sedimentary formations, and he shows, following other investigators, that these older glauconites, though still ferric, have greater percentages of ferrous iron than the recent types. The analyses also show a considerable increase in the amount of potash, and in some instances, at least, a diminution in the amount of alumina. Collet[12] remarks that "the glauconite which is forming today on the bottom of the sea is not the glauconite of sedimentary rocks, which certainly has undergone transformations that must be studied to understand the genesis of this interesting mineral." These transformations doubtless include the continuation of the process that he terms "glauconitization,' to which further reference is made on p. 563.

A group of analyses of glauconite from sedimentary rocks, some of which are identical with those given by Cayeux, are cited by Dana.[13] Some of these, together with analyses of material collected in the present investigation, are given in Table VI.

The separation of glauconite grains in the case of the last two samples was as nearly complete as it seems possible to obtain by the magnetic method. The potash content is distinctly higher than that of the other samples and is probably as high as could be expected from most New Jersey material.

Table VI. shows the general range and variety of composition of the older glauconites. By comparison of these analyses with

[11] *Loc. cit.*

[12] Collet, L. W., *op. cit.*, p. 168.

[13] Dana, J. D., and E. S., "System of Mineralogy," 6th ed., pp. 683, 684, 1914.

those of greensand given above it will be seen that much of the New Jersey greensand is nearly pure glauconite.

TABLE VI.

CHEMICAL COMPOSITION OF GLAUCONITE FROM OLDER SEDIMENTARY DEPOSITS.

	1.	2.	3.	4.	5.	6.	7.	G-7C.	G-13C.
SiO_2	49.42	51.24	49.76	50.62	50.42	46.91	49.09	50.58	49.47
Fe_2O_3	16.01	13.44	16.00	21.03	19.90	23.06	10.56	19.50	19.46
FeO	3.00	3.06	3.77	6.02	5.96	2.64	3.06	2.96	3.36
Al_2O_3	10.23	12.22	8.18	3.80	4.79	7.04	15.21	6.72	5.59
CaO	0.31	0.10	0.41	0.54[14]	3.21	2.95	0.55	0.34	0.60
MgO	3.78	3.93	3.97	0.57[14]	2.28	4.40	2.65	4.10	3.96
K_2O	7.91	7.50	7.57	7.14	7.87	7.31	6.05	8.26	8.04
Na_2O	0.26	0.31	0.52	—	0.21	0.91	1.21	0.04	0.16
CO_2	—	—	—	—	—	—	—	0.30	0.56
P_2O_5	—	—	—	—	—	—	—	0.27	1.06
H_2O	8.08	8.20	9.82	9.14	5.28	4.71	11.64	7.76	8.54
Insoluble material.	0.80	—	—	—	—	—	—	—	—
	99.80	100.00	100.00	98.86	99.92	99.93	100.02	100.83	100.80

1. Svir River, Russia, Kupffer, A., *Jahresb. Chemie,* 1870, p. 1307.
2. Ontika, Russia, Kupffer, A., *idem.*
3. Grodno Valley, Russia, Kupffer, A., *idem.*
4. Havre, France, Haushofer, K., *Jour. prakt. Chemie,* vol. 102, p. 38, 1866.
5. Antwerp, Belgium, Dewalque, F., *Soc. geol. Belgique Annales,* vol. 2, p. 3, 1877.
6. Gozzo Island, Mediterranean Sea. Bamberger, E., *Min. pet. Mitt.,* p. 271, 1877.
7. Ashgrove, near Elgin, Scotland. Heddle, M. F., *Roy. Soc. Edinburgh Trans.,* vol. 29, p. 79, 1879.

G-7C. Sewell, N. J., Hornertown marl, glauconite grains separated magnetically from the residues of washed greensand, see Table II.

G-13C. Elmwood Road, N. J., Hornerstown marl, glauconite grains separated magnetically from the residues of washed greensand.

Water-soluble Potash.— Since the water solubility of potash in greensand has an important bearing on the use of greensand as fertilizer or as an ingredient of prepared fertilizers, 18 samples were tested by R. K. Bailey and E. T. Erickson, of the United States Geological Survey laboratory. The method employed was that given in Bulletin 107 of the Association of Official Agricultural Chemists. The amounts of soluble potash in these samples ranged from a trace to 0.06 per cent.

[14] Carbonates.

Phosphoric Acid and Lime.—In the days when the marl industry flourished the importance of potash as a plant food was only beginning to be realized and the beneficial effects of the marl in agriculture were ascribed to its content of lime and phosphoric acid. In the light of the experiments of True and Geise[15] it now seems probable that the potash in the marl is sufficiently available to have agricultural importance at least equal to that of the phosphoric acid.

The average phosphoric acid content of New Jersey greensand marls as shown by 130 analyses given by Cook[16] is 1.78 per cent. Similarly the average lime content derived from 105 of Cook's analyses is 2.25 per cent. The highest individual percentage of phosphoric acid cited by him was 6.87 in a sample from the upper marl (Manasquan) from Poplar. The highest percentage of lime (not counting that reported as carbonate) was 15.19 in a sample from the lower bed (Navesink) from Holmdel. These results are higher than those obtained in the present investigation.

Analyses of three composite samples of Manasquan marl from the Birmingham-Pemberton district range from 1.37 to 3.58 per cent. of phosphoric acid and from 1.53 to 3.86 per cent. of lime. The average of 12 samples of the Hornerstown and Navesink marls gave 0.56 per cent. of phosphoric acid and 1.08 per cent. of lime.

The phosphoric acid and lime content of the three principal marl beds in New Jersey is relatively low but the Manasquan marl has a greater proportion of these substances than the other two beds. On the other hand, it contains less potash.

Accompanying Water.—At many localities the marl beds contain water. This is especially true of the southwestern part of the state where the elevations are generally lower than in the northeastern part. Much of the water has an unpleasant taste due to iron and sulphur and is unfit for drinking. One sample

[15] True, R. H., and Geise, F. W., "Experiments on the Value of Greensand as a Source of Potassium for Plant Culture," *Jour. Agr. Research*, Vol. 15, No. 9, pp. 483–492, Dec. 2, 1918.

[16] Cook, G. H., *op. cit.*, pp. 417–441.

of about two quarts was collected for analysis at Woodstown. A number of other samples, collected wet, were thought to contain sufficient water, singly or composite, to supply material for analysis. The waters, however, proved so dilute that the quantities available were insufficient for complete analyses.

Three partial analyses were made with the results shown in Table VII.

TABLE VII.

PARTIAL ANALYSES OF WATER SAMPLES FROM NEW JERSEY GREENSAND.

Sample No.....	15.	16.	24.
Locality.....	Elmwood Road, Hole 15.	Elmwood Road, Hole 16	Woodstown.
Soluble Salts.....	Per Cent. 0.029.	Per Cent. 0.0265.	Per Cent. 0 0088.
SiO_2.....	19.10	11.37	8.32
Ca.....	21.40	21.07	38.10
Na.....	8.23	9.35	13.20
K.....	3.33	3.80	5.97
Undetermined.....	47.94	54.41	34.41
	100.00	100.00	100.00

The percentages of soluble salts in the waters of Table VII. are so small that the apparently substantial amounts of potassium in samples 15, 16 and 24 correspond respectively to 9.6, 10, and 5.2 parts per million. This is probably far below the saturation point for potassium, for in the determinations of soluble potash mentioned above a maximum of .06 per cent. was obtained. This is equivalent to .05 per cent. potassium or 500 parts of potassium per million.

In laboratory determinations of water soluble potash it is customary to boil the material in water for perhaps half an hour to produce the solution, whereas in the ground solution takes place at a much lower temperature, and hence much more slowly. On the other hand, the water which percolates slowly through the beds has the advantage of long continued contact with the greensand. The disparity between the amount of potassium present and the amount required for saturation suggests that potassium is being withdrawn from solution. Other substances such as

vivianite, marcasite, iron carbonate, and phosphatic nodules have been or are being formed by the percolating waters.

SECONDARY ENRICHMENT.

Potash.—The borings show that the green marl averages 1.1 to 1.28 per cent. more in potash content than the other two beds. This difference appears to be due in part at least to its relatively less admixture of quartz. This is shown in the magnetic separations, Table II. Thus it is probably in the main a feature of original bedding rather than of subsequent enrichment. The green marl is usually distinct lithologically from the overlying or underlying beds. This again is probably a feature of original bedding.

At some localities, notably Sewell, there is clear evidence of leaching and oxidation of the upper part of the marl and consequent impoverishment in potash. Although the marl beneath has distinctly higher potash content, it is not clear that this is due to enrichment rather than to original deposition. At the Somerdale borings the Hornerstown marl has been in part eroded and is overlain by reworked marl of Quaternary age. This reworked marl is distinctly oxidized and contains less potash than the uneroded marl beneath, but this uneroded marl, which is part of the green bed, is not unduly high in potash.

Without doubt potash is locally being leached from the marl and is passing into solution. With little doubt, too, as suggested above, it is being abstracted from solution but there seems to be no readily distinguishable zone of enrichment unless the green marl bed be so considered. With regard to what becomes of this potash the following tentative suggestions are offered:

1. Clay, which is believed to have an important share in the formation of glauconite, was probably abundant in the original muds from which the glauconite was formed; witness the alumina present in all the analyses of glauconite and greensand cited above. It was probably more abundant in some beds than others. Thus the green marl bed with less quartz probably had a larger proportion of clay.

2. When the marl beds became part of the land area and were subjected to the action of meteoric waters the processes of oxidation and leaching of certain layers began. Some potash with other constituents went into solution and circulated through the marl beds. The potash-bearing solutions reacted with the clay to form new glauconite, the action being more pronounced in the more clayey layers, for example, the green marl bed. Some of the new glauconite formed additions to existing grains but some of it formed amorphous or colloidal glauconite, such as that which now constitutes so marked a feature of certain beds.

3. The difference in potash content between the recent glauconites and older glauconites shown in the tables above has significance in this connection, as does the remark of Collet cited with those tables. It seems quite possible that the development of glauconite, begun in muds off shore, may have continued by the process outlined above and may thus have enriched the undisturbed marl beds, through which the waters circulated.

4. The changes of level to which the marl beds, together with the entire coastal plain, have been subjected have permitted all the marl beds, even those that now lie above the water table, to be subjected to the action of ground water for protracted periods.

Other Substances.—Iron carbonate, somewhat phosphatic, forms a hard, stony layer at the base of the Hornerstown marl at one of the borings at Woodstown and probably also forms part of certain nodules and casts that are strongly phosphatic. The stony layer is localized at an horizon thought to mark the boundary between two formations. The nodules and casts are distributed rather irregularly. All bear witness to the activities of solution and deposition in the circulating waters.

Iron stone, or sedimentary material cemented by oxide of iron, occurs at many places and at a number of horizons, for example, at the pit of the R. S. Ryan Co. near Medford. Here it occurs along the contact between the Hornerstown marl and the overlying Quaternary gravels. This material also bears witness to the activities of ground waters. It is locally of sufficient abundance to be quarried as stone.

THIN SECTIONS OF GLAUCONITE.

A number of microscopic slides were made showing thin sections of glauconite and of some of the associated mineral grains of different sizes from the New Jersey borings. The noteworthy features of the glauconite, as shown in these sections are: (1) the absence of concentric or radio-fibrous structure; (2) the absence of any skeleton or core of other mineral matter; and (3) a uniform or nearly uniform aggregate structure of tiny crystalline flakes, which, in polarized light, show an aggregate polarization without general extinction.

The absence of skeleton or core is in distinct contradiction of the idea of Hart[17] that glauconite "consists of a core, which is apparently pure silica, and a covering layer of glauconite containing apparently no, or very little, silica."

Some grains, presumably those previously described as having a platy structure or cleavage, show these features with parallel extinction in thin sections and are pleochroic. These may prove to be crystals of glauconite like those described by Lacroix.[18] A grain of feldspar, in which flakes of glauconite had evidently been formed in cracks, was observed in one of the sections. The glauconite was apparently fresh and relatively pure and free from alteration. A few grains, however, showed encroachment of iron sulphide. The seed-like or capsule-shaped grains are isotropic. They are phosphatic and contain numerous tiny black particles that may be magnetite. Some of them contain grains of green glauconite. Plate XVIII. shows a number of glauconite grains in thin section, including one of the cleaved grains. The flaky texture is shown in some but others were too thick for successful photographing.

[17] Hart, Edward, "Glauconite or Greensand," *Jour. Am. Chem. Soc.*, vol. 39, p. 1919, Sept., 1917.

[18] Cited by Cayeux, Lucien, "Contribution à l'étude micrographique des terraines sédimentaires," *Mém. de la Soc. Géol. du Nord*, T. 4, 2, p. 165, 1897.

NOTES OF THE ORIGIN OF GLAUCONITE.

The origin of glauconite is still imperfectly understood. According to Murray and Renard,[19] organic matter inclosed in the shells and present in the mud itself transforms the iron in the mud into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated. The sulphur becomes oxidized into sulphuric acid, which decomposes the fine clay setting free colloid silica, alumina being removed in solution. The colloid silica and hydroxide of iron are in a condition most favorable for their combination and, in the presence of potash salts in sea water, these substances form glauconite. Collet[20] suggests in modification of these views three stages for which he cites evidence: (1) the formation of gray casts composed exclusively of clay; (2) brown casts of different shades representing different stages in the replacement of clay by peroxide of iron, no potash being present; (3) "glauconization," the introduction of potash and probably also of the water of constitution.

Murray and Renard[21] regard it as improbable that any minute grains of glauconite are formed in a free state in the mud. They think this mineral is formed in the cavities of calcareous organisms, though they admit that some grains appear to be highly altered fragments of ancient rocks, or coatings of glauconite on these rock fragments.

Cayeux[22] cites a variety of evidence to show that organic matter is not essential to the origin of glauconite grains. He ascribes an important share in their genesis to the so-called pigmentary glauconite and shows that grains of glauconite have originated or have continued to increase in size after all the elements of the accompanying sediments were in place as a consolidated deposit. He concludes that organic matter may be more often the primordial condition of the production of glauconite, but that it is very

[19] Murray, J., and Renard, A. F., "Challenger Rept., Deep Sea Deposits," p. 389, 1891.

[20] Collet, L. W., *op. cit.*, pp. 176–178.

[21] Murray, J., and Renard, A. F., *op. cit.*, pp. 387–388.

[22] Cayeux, L., *op. cit.*, pp. 176–184.

certain in many cases that organic matter has had no part in the genesis of this mineral.

Collet[23] also recognizes the important part that pigmentary glauconite may play in the origin of glauconite grains and adds that the absence of cement in microscopic sections of glauconite may be explained by the fact that both the glauconite grains and the glauconitic cement are cryptocrystalline and composed of particles differently oriented so that suture lines would be masked.

On p. 555 the fine material washed from the composite samples of New Jersey greensand beds is shown to contain approximately three to seven per cent. of potash. It consists largely of greenish to yellowish colloidal matter that may be classed as pigmentary glauconite. It may have been part of the original deposit, in which for some reason grains of glauconite did not develop, or it may have been formed by the mechanical wear or disintegration of previously existing grains. It may, however, have originated by the chemical action of circulating waters. Possibly grains of glauconite may be forming in it today, but of this no direct evidence was observed.

With reference to celadonite, a mineral closely related in composition to glauconite, Clarke[24] remarks:

> If, now, we assume that celandonite and glauconite are at bottom the same ferri-potassic silicate, differing only in their impurities, we may begin to see that the several modes of its formation are not absolutely different after all. Probably, in all their occurrences, the final reaction is the same, namely, the absorption of potassium and soluble silica by colloidal ferric hydroxide. In the ocean these materials are prepared by the action of decaying animal matter upon ferruginous clays and fragments of potassium-bearing silicates. In the sedimentary rocks, where glauconite appears as a late product the action of percolating waters upon the hydroxide would account for its formation. In igneous rocks the hydroxide is derived from augite, or perhaps from olivine. Thus the various productions of glauconite and celadonite become the results of a single process, which is exactly equivalent to that in which potassium compounds are taken up by clays. The observation of L.

[23] Collet, L. W., *op. cit.*, pp. 154–155.

[24] Clarke, F. W., "The Data of Geochemistry," 4th ed., U. S. Geol. Survey Bull. 695, p. 514–515, 1920.

Cayeux that glauconite is frequently present in arable soils, in all conditions from perfect freshness to complete alteration into limonite, suggests that perhaps the formation of the species is one of the modes by which potassium is withdrawn from its solution in the ground waters.

This statement tends to confirm the suggestions presented above in the discussion of enrichment.

SUMMARY.

Separation of New Jersey greensand by washing shows an average of 19.5 per cent. of fines in samples representing the entire thickness of the marl at six localities, favorably situated for commercial enterprise.

Magnetic separation of the residues shows that they contain on the average 89.9 per cent. of glauconite, and that the beds of unaltered greensand average 73 per cent. of glauconite grains. Much glauconitic material is also included in the fines.

The most common size of the glauconite grains is between one twentieth and one fortieth of an inch; of quartz, one twentieth to one sixtieth of an inch.

The shapes of glauconite grains are irregular, suggesting mechanical aggregation. The smaller grains resemble the larger but are more worn as if transported.

Chemical analyses of greensand show a silica content of about 50 per cent. and a relatively high content of ferric iron. The potash content of the Hornerstown marl is about double that of the Manasquan. Only small amounts of the carbonate and phosphate of lime are present but the Manasquan marl contains more of these substances than the Hornerstown or the Navesink.

Analyses of the coarse and fine products of wet separation show that these products have much the same composition. The potash content of the fines is about 0.1 to 1.5 per cent. lower than that of the unaltered marl.

Comparison of analyses of recently formed glauconites with those of glauconites from older sedimentary formations shows that the older glauconites though still ferric have a greater percentage of ferrous iron than the others and contain considerably more potash.

The better New Jersey greensand beds are composed of nearly pure glauconite.

The maximum amount of water soluble potash obtained in the analyses of 18 samples was .06 of 1 per cent.

The waters that circulate through the marl are very dilute but probably contain far less potassium than the amount required for saturation. The potassium is probably being withdrawn from solution. This action may produce enrichment throughout the marl beds but especially in the more clayey layers.

Thin sections of glauconite grains show them as masses of fine crystalline flakes without core, skeleton, or other structure.

Glauconite is not all formed through the agency of organic matter.

The greenish colloidal matter in greensand may be part of the original deposit, or may have originated by mechanical wear or disintegration of existing grains. It may have been formed by the chemical action of circulating waters. Clarke suggests that the formation of glauconite is one of the means by which potassium is withdrawn from solution in ground waters.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

THE R AND S MOLYBDENUM MINE, TOAS COUNTY, NEW MEXICO.

ESPER S. LARSEN AND CLARENCE S. ROSS.[1]

While engaged in geologic reconnaissance in the southern part of the San Luis Valley for the United States Geological Survey under the direction of Whitman Cross during the fall of 1919, and incidental to this work the authors visited the interesting molybdenum mine near Questa in the north part of New Mexico. The following brief description of the mine and its geology is a result of this visit. Only one day was devoted to the area, and for this reason it was not found possible to study all of the important details and many problems concerning the origin of the ore remain unsolved.

LOCATION AND TOPOGRAPHY.

The R and S molybdenum mine is located in the western part of the Culebra Range in Toas County, New Mexico, on Sulphur Gulch, a northern branch of Red River, a stream that flows in a westerly direction until it empties into the Rio Grande. It lies about 8 miles up the river from Questa, N. Mex., and about 27 miles from Jarosa, Colo., on the San Luis Southern Railway. The mine lies at an elevation of about 8,700 feet above the sea level. The topography is sharp and near the mine the slopes on either side of Sulphur Gulch form almost shear cliffs. The streams have steep grades and erosion is proceeding at a rapid rate in the soft, altered rocks.

HISTORY.

The yellow molybdic ocher that formed as an alteration product at the outcrop of the veins was long regarded as sulphur and gave

[1] Published with the permission of the Director of the U. S. Geol. Survey.

the name to the gulch on which the mine is situated. About the time of the entry of the United States into the war it was realized that the black substance associated with the "sulphur" was not "graphite" but molybdenite, and the Western Molybdenum Company of La Jara, Colorado, was organized to develop the prospect. No systematic development work was done by this company and no ore was produced. In November, 1918, the R and S Molybdenum Company of Denver was formed and took over seven claims from the Western Molybdenum Company and the new company has filed additional claims to increase the total holdings to about 300 acres. Development work was prosecuted throughout the winter, production began in the spring and was continuing at the time of the visit.

EQUIPMENT AND DEVELOPMENT.

The buildings at the mine were an office, bunk house, ore sorting shed, and a blacksmith shop. The company has built a mile of good road to connect the mine with the main road on Red River. A remodeled gold mill operated by water power, situated five miles from the mine, is being used at the present time, involving a haul of ore by auto truck. The equipment at the mill consists of a jaw crusher, ball mill, classifier, and flotation plant.

A tunnel has been driven for 300 feet along one of the southernmost of the group of veins exposed on the property, and in places this has been stoped to a height of 60 feet. Only enough ore has been withdrawn to allow the work to proceed and considerable broken ore was still in the mine in September. The ore as it comes from the stopes is said to average about 2 per cent of MoS_2. This material is run over the grizzly and the fines go directly to the ore bins. The coarse material is hand sorted and the tenor of the ore raised to about 4 per cent. Concentrates run from 80 to 91 per cent. MoS_2 and no trouble is experienced in producing 90 per cent. concentrates. The concentrates are said to be low in copper and phosphorus.

GEOLOGY.

The rocks of the region are a soda-potash alaskite porphyry in which the ore occurs, a dark gray granodiorite porphyry, and volcanic tuffs and flows.

The alaskite porphyry at the mine is a pale flesh pink rock of medium grain having phenocrysts with a maximum diameter of about 4 mm. The following is the approximate mineral composition:

Quartz	32.00
Orthoclase	20.00
Albite	47.00
Magnetite	0.50
Chlorite	0.20

Insignificant amounts of apatite and zircon were observed. This is a rather unusual granite in that felsic minerals form fully 99 per cent. of the rock mass, and since it is composed almost entirely of quartz and alkalic feldspars it should be classified as an alaskite. The orthoclase occurs in large anhedral grains, and contains a few lenses of microperthitic albite. The albite occurs in euhedral gains and has approximately the composition $Ab_{88}An_{12}$. Both feldspars contain many flakes of secondary mica and chlorite, the latter of which is especially abundant near the magnetite grains. Secondary calcite and pyrite occur in tiny veinlets which were evidently introduced after the final crystallization of the rock. Another specimen of alaskite collected at the mine has approximately the same mineral composition given above, but it is composed of phenocrysts of partially resorbed quartz, orthoclase and albite in a fine-grained ground mass of microperthitic quartz and albite. This alaskite appears to form a considerable body as similar rock, with somewhat larger phenocrysts and more and fresher biotite forms the lower canyon of Red River.

In general the alaskite of the area is only moderately altered to sericite even in the immediate vicinity of the system of veins, but one-fourth mile up the gulch there is a large area of alaskite more than a mile across which is decomposed to a soft easily eroded

rock. The water of the north branch of the creek which crosses this area is highly impregnated with alum and iron sulphates.

The dark gray granodiorite porphyry occurs in large masses which appear to be included near the top of the alaskite, and it is clearly intruded by the alaskite. This rock is everywhere considerably altered. It is made up about half of stout crystals of plagioclase about a millimeter in length that are now changed to albite with much sericite, imbedded in a finer grained matrix of quartz and orthoclase. There is considerable chlorite and sulphides. Silicification has occurred throughout the rock and small bands are present where all the minerals composing it have been changed to a mass of interlocking quartz grains. Veinlets of calcite and pyrite are even more common than in the alaskite.

The alaskite and the granodiorite are overlain by volcanic tuffs and flows, which are much altered to sericite where seen. They were mostly rocks with large quartz and feldspar phenocrysts, probably quartz latite and andesite. The rapid erosion in these sericitized areas has exposed large patches of white and iron-stained rock that can be seen on the mountain sides for many miles.

VEINS.

The alaskite has been sheeted for about a thousand feet in a north south direction along Sulphur Gulch and this sheeting is said to extend for several thousand feet in an east–west direction. There are a number of main fractures which are approximately parallel and strike about N. 79° W. The veins are all the result of mineralization along these fracture and shear zones. The larger ones follow the main shear zones, but smaller veins and flats branch, intersect, and reunite forming a very complex network. Yellow molybdic ocher makes the outcrop of the veins conspicuous and easily traced. Development work has been confined almost entirely to one vein near the southern border of the group, but its surface indications were no more promising than those of several other veins. In the 300-foot tunnel the mineralized zone has been rather constant in its characteristics, varying

in width from 4 to 6 feet. The ore zone is shattered and sheeted alaskite with the ore filling the fracture. Small veins and films of ore penetrate the wall rock but there is almost no replacement of the alaskite and so very little molybdenite is found disseminated in it.

The large persistent veins do not appear to extend far into the granodiorite porphyry, although small veins and stringers of ore are common in that rock. This is at least partly due to the fact that the granodiorite is closely fractured resulting in a greater dissemination of the ore-bearing solutions entering it. No mineralization of the volcanic rocks of the region was observed.

In general mineralized shear zones do not result in ore bodies that are remarkable for their persistence. In the R and S mine, however, one vein at least has been rather uniform throughout the 300 feet of its development, but in spite of this it seems doubtful if single ore shoots can be expected to continue for long distances. It seems likely that there will be more or less lenticular ore bodies that will pinch out, possibly to be followed by other similar ones farther along the shear zone. If this is the case these succeeding lenses might be found either on the strike of the first lens or offset from it, and small veins or stringers would be likely to connect them. One would not expect marked changes in the character of the ore with increasing depth, but there would probably be that same lack of marked continuity in vertical as in lateral extent.

THE ORE.

The mineralized zone which is being stoped contains a comparatively small porportion of vein-filling, as sericitized alaskite lies between the small branching veins. This vein-filling is made up mostly of quartz with a large proportion of molybdenite, some pyrite, a little chalcopyrite, fluorite, sericite, apatite, biotite, chlorite, and calcite. The relationships show that the alaskite was thoroughly sheeted before the introduction of the vein minerals, but that minor movements continued up to the time of the deposition of calcite, the last mineral to form.

Quartz occurs as scattered grains in the sericitized alaskite and as vein-like masses four or more inches in width. In the larger vein masses the less abundant minerals occur in zones in the quartz giving it a banded structure. Fluorite is common in parts of the mine, but does not form an important gangue mineral. The color varies from brownish red to pale green, and zonal color variations are common in the larger grains. A vein of fluorite several inches thick crosses Sulphur Creek about 200 yards above the mine. Pyrite is not abundant but is present in the veins and all the country rocks of the region that have been studied. Biotite which occurs in large masses is normally dark brown in the hand specimen and pale brown in the thin section. Some of it is bleached and other portions are partly altered to green chlorite. It forms layers near the borders of the veins with the plates which are commonly a centimeter across arranged perpendicular to the layers. It appears to be clearly associated with the molybdenite. Apatite forms large irregular masses and is rather common in many of the thin sections examined. Calcite occurs in veinlets filling fractures in the older vein minerals. Molybdenite constitutes the only mineral of value in the veins. It is found in bodies varying in size from the smallest films and flakes up to irregular lens-shaped masses 5 or more inches in thickness. These masses all have a distinctly lamellar structure and the molybdenite occurs in distinct flakes. The larger bodies which are commonly found at the intersection of veins, appear on casual examination to be composed of very pure molybdenite, but a study of polished surfaces shows them to be made up of molybdenite disseminated in masses of quartz or sericite and only subordinately of pure flake molybdenite. The larger masses are commonly slickensided.

Erosion in the region has been so rapid that the oxidized mantle at the outcrop of the veins is very thin varying in thickness from a few inches to a maximum of a few feet. The only oxidation minerals observed were molybdic ocher ($Fe_2O_3.3Mo_3.7\frac{1}{2}H_2O$) resulting from the alteration of molybdenite, and small amounts of limonite derived from pyrite.

ORIGIN OF THE ORES.

Molybdenite is generally regarded as a primary mineral deposited by magmatic waters, but it has been described from deposits that have been formed at vastly different depths and at very different temperatures. In the R and S mine its association with pyrite, fluorite, sericite, biotite, and quartz in a mineralized shear zone indicates that the ore has been formed by ascending magmatic waters, probably at a moderate temperature.

CONCLUSION.

As yet molybdenum ore has been found in only a comparatively small area in Sulphur Gulch. The veins are in a zone of shearing in an alaskite and there appears to be a number of veins that promise to be of sufficient width for economical mining, and many smaller stringers. The veins are of a kind that not uncommonly lack persistence and it is not safe to assume a continuation of the ore bodies much beyond the developed areas. However, the 300-foot tunnel exposes several thousand tons of ore and the chance of considerable more ore in the vein prospected by the tunnel and in some of the other veins seems good. The ore exposed in the main tunnel is of very good and of rather uniform grade.

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SOME CANADIAN OCCURRENCES OF PYRITIC DEPOSITS IN METAMORPHIC ROCKS.

GEORGE HANSON.

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INTRODUCTORY.

This paper is the outcome of an attempt to discover what relation the form and structure of pyritic deposits bear to the nature of the enclosing rocks, and whether similarities in form and structure are related in origin. Further, it was hoped that the data obtained during the study would be of some value in helping to clarify some of the general problems connected with the origin of these ore bodies.

A few examples of ore bodies of this general type in Canada were studied in the field and in the laboratory. In trying to deduce explanations for the phenomena observed, specimens from other ore bodies which show many points of similarity were studied. This has brought out the fact that many of the similarities observed, particularly in regard to form and structure, may be produced by different causes.

The laboratory study was carried out in the laboratories of the Massachusetts Institute of Technology. The writer is especially indebted to Dr. Lindgren for helpful criticism and to Dr. Bruce of Queens University for the loan of ore specimens.

THE SULPHIDE DEPOSITS OF NORTHERN MANITOBA.

Location.

The sulphide ore bodies of northern Manitoba to be discussed in this paper are in the vicinity of Schist Lake, about 400 miles northwest of Winnipeg and 70 miles north of The Pas, Manitoba. Schist Lake is reached most conveniently from The Pas, where the Hudson Bay Railway crosses the Saskatchewan River.

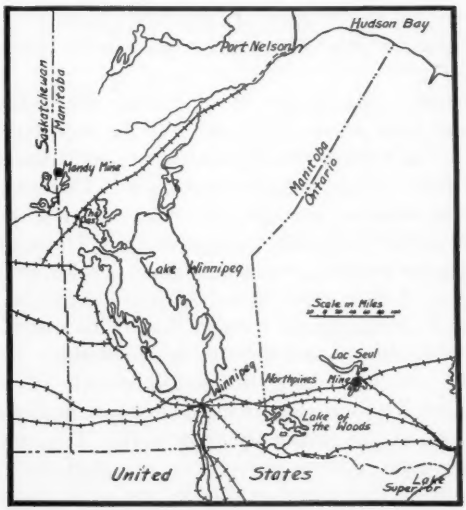


FIG. 61. Index map showing location of the Mandy and Northpine Mines.

From The Pas, during the summer months, travel is by steamboat up the Saskatchewan River to Cumberland House, across Cumberland Lake and Sturgeon Lake to Sturgeon Landing at

the mouth of the Sturgeon River. From here the route is either by wagon road to Schist Lake or by canoe via Sturgeon River, Goose River, Goose Lake, and Athapapuskow Lake.

Geology.

The Schist Lake area is of slight relief and is characterized by the low rock ridges and intervening lakes and marshes so typical of the Canadian Shield. Rocky prominences rarely rise to elevations of 100 feet above the level of the lakes. The geology of the district is complex. The area is underlain by metamorphosed igneous and sedimentary rocks of early Pre-Cambrian age and by later Pre-Combrian granite. To the south, the Pre-Cambrian complex is overlain by gently dipping Ordovician dolomite. Pleistocene and Recent rocks are practically lacking.

The following table of formations has recently been published by Bruce.[1]

The Amisk volcanics are of widespread distribution in the district and form the country rock of all the important sulphide deposits. The rocks are chiefly metamorphosed lavas, agglomerates, and tuffs, of intermediate composition. The flows are represented by massive greenstones, which in some places are ellipsoidal and in a few places, amygdaloidal. The agglomerates contain angular rock fragments, light green in color, embedded in a matrix of darker green material. The composition of the fragments is practically the same as that of the matrix, but the latter is more sheared and contains more chlorite. The greenstones and schists are composed almost entirely of secondary minerals, and it is impossible, in many instances, to determine the exact nature of the pre-metamorphic rock. Thin sections of greenstone show altered phenocrysts of plagioclase. Other minerals present are abundant chlorite and often abundant calcite; epidote and zoisite in variable quantity; always minor quantities of quartz and magnetite; and sometimes small amounts of pyrite. The matrix of the agglomerate shows a similar min-

[1] Bruce, E. L., "The Amisk-Athapapuskow Lake District," Geol. Surv., Can. Mem. 105, p. 9, 1918.

TABLE OF FORMATIONS.

Quaternary	Recent Pleistocene	Peat, river alluvials Lake silts, till, sand, gravel
	Unconformity	
Paleozoic	Ordovician	Dolomite.
	Unconformity	
Pre-Cambrian		Kaminis granite Granite gneiss Hybrid granite rocks
	Intrusive contact	
	Upper Mississippic series	Arkose Conglomerate
	Unconformity (?)	
	Lower Mississippic series	Slate Greywacke Quartzite Conglomerate
	Unconformity	
		Cliff Lake granite porphyry
	Intrusive contact	
	Kisseynew Gneisses	Sedimentary and igneous gneisses and schists
	Amisk series	Lavas, tuffs, agglomerates and derived schists

eral composition. It is probable that the fissile chlorite schists represent fine-grained and less competent beds such as tuffs.

The Kaminis granite occurs as extensive batholithic intrusions. All gradations from granite to granodiorite are found. A thin section of the granite from the west side of Phantom Lake contained the following minerals: quartz, orthoclase, microcline, albite-oligoclase, hornblende, biotite, apatite, titanite, magnetite, zircon, chlorite, zoisite, epidote, and sericite. The alteration products are rare.

Since the other formations in the area are of local occurrence and are not believed to be genetically related to the ore deposits, they will not be described.

The structure of the Amisk volcanics has not been worked out. The planes of schistosity are everywhere vertical or steeply dipping and the strike is in general, north-south, always being parallel or nearly so, to the contact with the larger areas of younger granite.

For complete discussion of the geology and structure see the following publications.[2]

Ore Deposits.

The sulphide deposits can be grouped into two classes.

1. Those consisting chiefly of pyrite, chalcopyrite, and sphalerite.
2. Those consisting chiefly of pyrrhotite.

The important discoveries up to the present, are all of the first type. They occur as well-defined lenticular veins and lenses in a country rock of Amisk volcanics. The ends of the ore bodies show in general, several vein-like extensions which in turn split up into smaller veins and pinch out. The ores have been formed chiefly by replacement in zones of more intense shearing and brecciation and are, consequently, elongated along the strike and dip of the planes of schistosity of the enclosing rocks. The mineralized zone in the smaller sulphide bodies is only slightly more schistose than the adjoining country rock and consists of several parallel sulphide veins, usually less than 18 inches in width, separated by bands of schist.

The ore bodies apparently represent mineralization in sheared and brecciated zones. The larger ore bodies differ from the smaller ones in that they represent more intense conditions of replacement and were formed in more strongly sheared zones. Small sulphide deposits are often found at the contacts between

[2] Bruce, E. L., "The Amisk-Athapapuskow Lake District," Geol. Surv., Can. Mem. 105, 1918.

Wallace, R. C., "Mining and Mineral Prospects in Northern Manitoba," 1920.

the Amisk rocks and the later granites, but the larger deposits are at some distance from the granite intrusions. The ore bodies are believed to be genetically connected with the granites of the region.

THE MANDY MINE.

The Mandy Mine is situated on a narrow point on the west shore of the northwest arm of Schist Lake, about 2 miles from the north end of the lake. The rocks exposed on the point are greenstones, chlorite schists, and pyroclastic rocks. They are similar to the rocks previously described. Granite outcrops about 2 miles to the southwest, on Phantom Lake. Granite porphyry is exposed about 2 miles to the southwest, on Hook Lake, and also 4 miles to the north, near Ross Lake. Granite dikes occur east of the northwest arm of Schist Lake. Wallace states that disseminated arsenopyrite is characteristic in the granites of the region.[3]

The Ore Body.

History of Development and Production.—The Mandy ore deposits were discovered and located in the autumn of 1915. The ore body proved to be of sufficient size and richness to permit mining under very adverse conditions of transportation. The ore was hauled 35 miles by teams to Sturgeon Lake. From here it was taken on scows to The Pas, a distance of 120 miles. It was then transported by rail to the smelter at Trail, British Columbia. Mining has reached a depth of 250 feet.

Production, in view of the transportation difficulties is rather surprising. The mine produced 1,116,000 pounds of copper in 1917, and 2,339,750 pounds in 1918.[4]

General Character of the Deposit.—The plan of the ore body shows the distribution of ore in a general way. The ore body is in the form of an irregular lens 225 feet long and 40 feet wide

[3] Wallace, R. C., "Sulphide Deposits of Flinflon and Schist Lakes, Man.," *Can. Min. Jr.*, vol. 37, p. 468, 1916.

[4] McLeish, J., "The Production of Copper, Lead, Nickel, etc., in Canada during the Calendar Year 1918," Dept. of Mines, Can., No. 527, p. 12, 1919.

at its widest point. The deposit is included in a band of chlorite schist between two bands of massive greenstone. At the northwest side a two-foot vein continues to the north along the strike of the rocks and consists chiefly of pyrite. At the southeast side is a similar vein containing chalcopyrite as the predominant sulphide. Where the ore body pinches out to the north it has split into several narrow veins. The lens is elongated along the strike of the schists. It dips steeply to the east and pitches

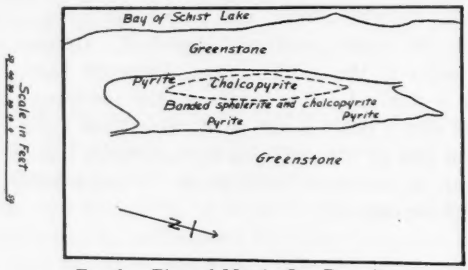


FIG. 62. Plan of Mandy Ore Deposit.

steeply to the south. Bruce suggests as an explanation of the shape of the ore body and its relation to the greenstone bands, the theory that the more easily replaced zone in which the ore is found originated through drag folding of the less competent schistose band. He states further, that a fault continues northward from the ore body and follows the general strike of the schistosity.[5]

Mineralogy.—The metallic minerals identified, named in their order of deposition, are pyrite and arsenopyrite; sphalerite and chalcopyrite; galena. Products of oxidation such as limonite, malachite, and chalcanthite, are present at the surface. The ore contains small amounts of gold and silver. Gangue consists of small residual lenses of country rock and quartz, calcite, dolo-

[5] *Op. cit.*, pp. 74–75. (See also: "Chalcopyrite Deposits in Northern Manitoba," E. L. Bruce, ECON. GEOL., Vol. 15, p. 386, 1920, which appeared while Mr. Hanson's paper was in press.—ED.)

mite, and chlorite, but the total amount of gangue forms a very small proportion of the whole deposit.

Arsenopyrite, though not present in any great quantity, is of widespread distribution in the form of small grains or crystals in the ore body. Pyrite and arsenopyrite are in general contemporaneous, but in a few places it can be seen that pyrite is, in part, earlier than arsenopyrite.

Pyrite occurs as cubes and as rounded and irregular grains. Some specimens show that this mineral is fractured and the cracks filled with later minerals. In several places, the structure shows that this fracturing was the result of pressure after the formation of the ore deposit, as the later minerals curve inward and fill the fractures and also curve around unbroken pyrite grains. Some areas of pyrite show the "exploded bomb"[6] structure, and here the pyrite appears to have been partially replaced by chalcopyrite. Some specimens show no evidence of post-ore deformation. Minute cubes of pyrite were observed included in chalcopyrite, and it is believed that these cubes were not formed at the early pyrite stage but represent local crystallization with the chalcopyrite.

Chalcopyrite is very common as a cement between pyrite grains. In the banded ore it contains small blebs of sphalerite and numerous grains of pyrite or arsenopyrite. The sphalerite is of the dark-brown to black variety and occurs as a cement between pyrite grains and in bands with chalcopyrite. These two minerals are, in many places, intimately intergrown and are apparently contemporaneous. Where they are found together as a matrix to the pyrite grains, the one which is the more abundant appears to be the earlier. Galena is rare and is found as inclusions in the chalcopyrite and sphalerite.

The gold is contained in the chalcopyrite, and the silver in the sphalerite.[7]

The age relation between the gangue minerals is rather indefinite. Quartz and carbonates had a long period of formation.

[6] Graton and Murdoch, "The Sulphide Ores of Copper," *A. I. M. E.*, p. 752, February, 1913.

[7] Bruce, E. L., Geol. Surv., Can. Summ. Rept., p. 165, 1916.

They are often interstitial between pyrite grains, and in some places, fill cracks in the pyrite. Quartz is later than pyrite and may be earlier than, or contemporaneous with, sphalerite and chalcopyrite. Dolomite, which is rare, is in part earlier than the later sulphides, but the greater part of the carbonates, chiefly calcite, and some quartz is later than the sulphides. Minute laths of chlorite, included in the sphalerite of the banded ore, are arranged parallel to the banding of the sulphides and are rather common. They may be residual parts of replaced schist, or they may have been deposited from the ore solutions. Since they show no evidence of having been partially replaced, and since there is no other rock mineral associated with them, it is concluded that this chlorite was deposited from the ore solutions.

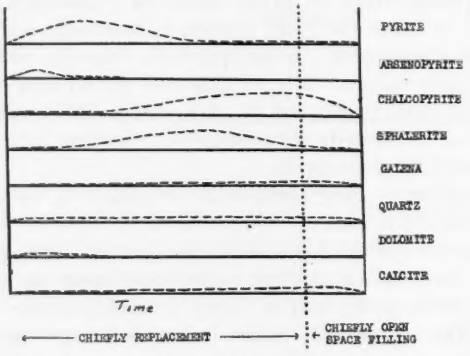


FIG. 63. Mandy Mine. Curve showing order of deposition of minerals.

Alteration of Wall Rock.—The chlorite schist in which the ore body lies is composed of secondary minerals, and it is difficult to determine to what extent alteration is due to metamorphism before ore deposition, and to what extent the secondary minerals have been formed by the ore solutions. The wall rocks, however, are softened, impregnated with pyrite, and converted into fissile sericitic schists. This markedly altered zone varies from a fraction of an inch to a foot in thickness. The hanging wall is more thoroughly altered than the foot wall.

Thin sections show that sericite is the common hydrothermal mineral found in the wall rocks. Calcite is fairly abundant and is commonly found in little veinlets which usually contains a good deal of pyrite. Quartz is also present and usually occurs in vein-like zones parallel to the schistosity of the country rock. The quartzose zones always contain pyrite. Small groups of minute prisms of rutile were found in all the thin sections of wall rock.

The country rock contains feldspar, a great deal of epidote, and some magnetite. The altered wall rocks contain no feldspar, epidote, nor magnetite. Rutile was not observed in specimens of ordinary country rock.

The minerals that have been developed in the wall rocks by the ore solutions are sericite, carbonates, pyrite, chlorite, quartz, and rutile. It is not held that all of the carbonate, chlorite, and quartz, were introduced by the ore solutions, but the occasional occurrence of these minerals in veinlets suggests that they have been, in part, introduced. Magnetite, present in ordinary country rock but not found in the wall rock, has probably been converted into pyrite. The exact nature and quantity of the constituents introduced has not been determined quantitatively, but it is apparent, that there has been some introduction of potassium, sulphur, quartz, and pyrite. It is probable also that there has been some introduction of magnesium, calcium, and carbon dioxide. In the more intensely altered material there has been some dehydration.

Structure of the Ore.—Along the footwall of the ore body is a zone, varying from a few inches to 12 feet in width, consisting chiefly of pyrite. Next comes a lens-shaped body of almost pure chalcopyrite, with a maximum width of 12 feet. This is succeeded on the east by 10 feet of banded sulphides and some country rock. Finally, there is a zone of pyrite about 8 feet wide along the hanging wall. The footwall zone is well marked and consists of pyrite with a little sphalerite and chalcopyrite. The chalcopyrite lens, where it borders on the pyrite zone, is well defined. Where it borders on the banded zone it shows

gradational facies to banded ore. The lens does not extend to the ends of the sulphide deposit but is completely surrounded by pyrite and sphalerite. The strike of the lens is not exactly the same as that of the deposit as a whole. The zones between the lens of chalcopyrite and the hanging wall are not so definite. The pyrite zone grades into country rock and contains much sphalerite and chalcopyrite. The banded zone consists chiefly of sphalerite but also contains much chalcopyrite interbanded in thin seams with similar seams of sphalerite, and as definite veins a few inches in width. Pyrite is also fairly common, and bands of country rock are present.

The fine banding is particularly pronounced in this sphalerite zone. The banding is roughly parallel to the strike of the ore body, and is produced by alternating seams of sphalerite and chalcopyrite. Numerous bands are about a quarter of an inch in width, and some are too thin to be seen megascopically.

Specimens from the pyritic zones show equidimensional cubes and grains of pyrite and some arsenopyrite, cemented by chalcopyrite, sphalerite, quartz, and carbonate. Included lenses of schist are small and uncommon, but where they are present, the schistosity and elongation are always parallel to the schistosity of the country rock. A rough banded appearance in the pyrite zones is produced by bands of pyrite, bands where the matrix is chiefly chalcopyrite, and others where sphalerite is the predominant constituent in the matrix. The pyrite shows very little if any corrosion and replacement by the later constituents.

The chalcopyrite lens contains many small inclusions of all the other minerals found in the ore.

In the well-marked bands of the sphalerite zone, the chalcopyrite layers usually contain numerous grains of pyrite and some arsenopyrite, often arranged in a line along the center of the layer, and a few blebs of sphalerite. Here the pyrite has been partially replaced by chalcopyrite. The sphalerite layers contain less pyrite, but they do contain numerous minute laths of chlorite. The sphalerite in all places contains a notable content of chalcopyrite, present as irregular branching areas, a structure com-

monly observed in ore deposits containing these minerals. All gradations were observed between areas showing chalcopyrite as inclusions in sphalterite, and areas showing sphalerite as inclusions in chalcopyrite. This type of structure has been discussed recently by L. P. Teas, and he believes that the chalcopyrite is in general later than the sphalerite.[8] In the Mandy Mine, however, these two minerals are intergrown and are apparently contemporaneous (Figs. 61, 62, 63).

Genesis.—In the literature, the Mandy ore body has been ascribed to hydrothermal solutions connected with granite intrusions, by all who have put forward theories regarding its origin. Bruce regards the wall rock alteration as hydrothermal and points out that sulphide deposits are common in the district along the borders of dikes and small bosses of granite. Wallace notes the universal presence of arsenopyrite in the granites of the region as evidence that the mineralization has been caused by the granite intrusions.

The gangue minerals, and the minerals developed in the wall rocks, are most common in deposits formed at intermediate temperatures and pressures. It is believed that pyritic deposits in general are formed at considerable depths. At the Mandy Mine arsenopyrite is universal in the ore, and no typical low temperature minerals are present. It is concluded that intermediate to high temperatures prevailed during ore deposition.

Selective replacement of schistose rocks has been advocated to explain the fine banding of the chalcopyrite and sphalerite.[9] To explain similar banding in the ores at Rammelsberg, Germany, post-ore deformation and the squeezing out into bands of the minerals sphalerite and chalcopyrite, has been emphasized.[10] The Rammelsberg ore, however, shows very marked evidence of post-ore deformation. At the Mandy Mine there has been some

[8] Teas, L. P., "The Relation of Sphalerite to other Sulphides in Ores," *Bull. Amer. Inst. Min. Engrs.*, pp. 1917–1931, February, 1918.

[9] Bruce, E. L., "The Amisk-Athapapuskow Lake District," Geol. Surv., Can., Mem. 105, pp. 71–76, 1918.

[10] Lindgren and Irving, "The Origin of the Rammelsberg Ore Deposit," Econ. Geol., vol. 6, pp. 311–313, 1911.

late deformation but probably not enough to squeeze out the zinc and copper sulphides into bands.

The development of foliation and fissility in gneisses and schists is due to the development of platy minerals in the rock. Thinly bedded slates and quartzites may be squeezed out resulting in a finely-banded gneiss or schist, consisting of slate and quartzite bands, but the slates and quartzites were in bands before the squeezing took place. Chalcopyrite and sphalerite are not platy minerals and probably would not form bands in the same manner as the platy minerals in a foliated rock. Further, it is unlikely that they would be squeezed out into long pure bands of each mineral unless they existed side by side in a pure state before deformation. It would seem that deformation might transform an intimately mixed chalcopyrite-sphalerite ore into a banded ore, but the bands would be short and discontinuous.

In the galena veins in the Slocan District, British Columbia, as a result of post-ore deformation, the galena is gneissose and the included sulphides are drawn out.[11] The inclusions of chalcopyrite in the sphalerite of the banded ore at Rammelsberg are elongated parallel to the banding. Similar inclusions in the Mandy ore are not orientated parallel to the bands, and it is not believed that post-ore deformation has played any part in the development of the banding.

It is believed that the solutions ascended in a sheared and brecciated zone depositing at first chiefly pyrite, thus forming the pyrite zones and numerous thin seams of pyrite in the less permeable schist. Slight shearing and fracturing continued while the solutions were becoming richer in sphalerite, chalcopyrite, and gangue minerals. It is believed that the banded zone was formed at this intermediate to late stage. Many chalcopyrite bands have a row of pyrite grains along the center, but the sphalerite bands contain very little pyrite. Since the chalcopyrite and sphalerite appear to be contemporaneous, it would appear that the former mineral was precipitated more easily than the latter, by the pyrite. In the latest stages, chalcopyrite was

[11] Uglow, W. L., "Gneissic Galena Ore from the Slocan District, British Columbia," ECON. GEOL., No. 8, pp. 643-662, 1917.

predominant and filled fractures. In this last stage would come the chalcopyrite lens and the veins cutting the sphalerite zone. It is believed that in the early stages, replacement was important and filling of open space of minor importance; in the latest stages, replacement was less pronounced, and open space filling was becoming predominant.

THE FLINFLON ORE BODY.

General Description.

The ore body at Flinflon Lake lies along the east shore near the south end of the lake. This deposit is about 4 miles northwest of the Mandy Mine. The sulphides outcrop on a point projecting into the lake and also along the shore 800 feet farther north. Between the two places the ore body underlies the lake. East of the ore body are ridges of massive greenstone trending along the strike of the foliation.

The country rock is made up chiefly by the Amisk series. Massive, ellipsoidal greenstone outcrops east of the ore zone and also southwest of the lake. A trench exposes a narrow dike of fine-grained quartz porphyry along the east side of the ore body. A large horse of barren rock in the ore consists of massive and amygdaloidal greenstone and a basic dike which was probably intruded in late Amisk time. The strike of the schistosity is roughly north and south and the dip is steep to the east. Granite outcrops 4 miles south and southwest, 1½ miles west, and 3 miles north. The rocks associated with the ore deposit are similar to those previously described.

The Ore Body.

History of Development.—The Flinflon sulphide deposit was discovered in 1915. Cross trenching showed a considerable width of sulphide and development continued by means of diamond drilling. The ore is too low grade to mine with the present means of transportation.

General Character of the Ore Body.—Owing to the fact that

there has been no underground development except by diamond drill from which no data were obtained, and that the surface exposures were very unsatisfactory, no clear idea could be obtained of the general structure of the ore body. Consequently, description will be brief.

The ore lies in a sheared zone in rocks of the Amisk series. The large greenstone horse separates two zones of sulphide 55 feet and 30 feet wide. South of the horse there is one zone of sulphides 75 feet wide. Diamond drilling has proved that the length of the ore zone near the surface is over 2,500 feet and over 1,000 feet at a depth of 900 feet. The ore is massive pyritic sulphide. At the surface, where oxidation has been effective, only a friable mass of pyrite, quartz, and limonite, remains. Bruce states that the footwall side of the ore zone is mostly pyrite. Eastward, bands of fine-grained black sphalerite and a little galena begin to appear. Nearer the hanging wall bands of chalcopyrite are present.[12]

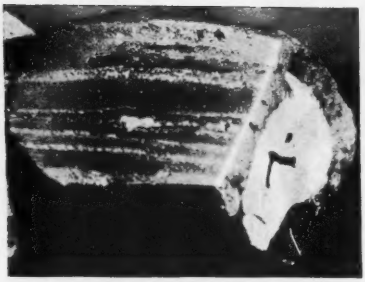
Mineralogy.—The minerals identified in polished specimens are pyrite, arsenopyrite, sphalerite, chalcopyrite, and galena. Magnetite has recently been recorded.[13] Gold and silver are obtained from the assays of the ore. The minerals occur in the same manner as in the pyritic zones at the Mandy Mine. Sphalerite and galena are more prominent and chalcopyrite less common than at the Mandy Mine. The Flinflon ore is very fine grained. Plate XX, *a* shows the typical structure of the ore.

Gangue is rare and consists of fragments of schist and the minerals quartz and calcite. Quartz is present interstitially between grains of pyrite and appears to have been deposited in general later than the pyrite and at about the same time as sphalerite. Calcite is associated with quartz and is rare.

Wall Rock Alteration.—There has been considerable impregnation by pyrite to a distance of 15 feet from the ore, and there is usually a gradation from country rock through rock heavily impregnated with pyrite, to the sulphides of the ore zone. Near

[12] Bruce, E. L., "The Amisk-Athapapuskow Lake District," Mem. 105, Geol. Surv., Can., pp. 69–72, 1918.

[13] Wallace, R. C., *op. cit.*, p. 22.



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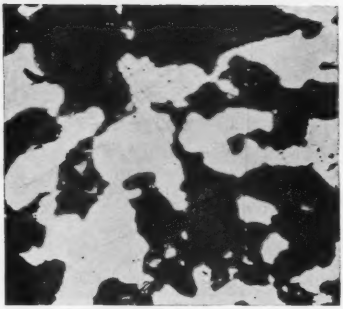

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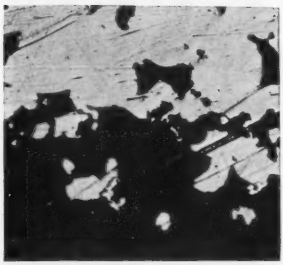

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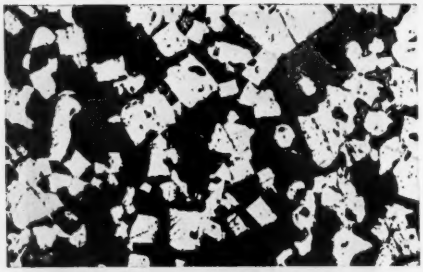
a. Mandy Mine, Manitoba. Banded chalcopyrite (white) and sphalerite (dark-gray). Polished section (× 3).

b. Mandy Mine. Intergrowth of chalcopyrite (white) and sphalerite (dark-gray) in band consisting chiefly of sphalerite. Polished section (× 550).

c. Mandy Mine. Contact between two bands. Chalcopyrite (light-gray) and sphalerite (dark-gray). Polished section (× 500).



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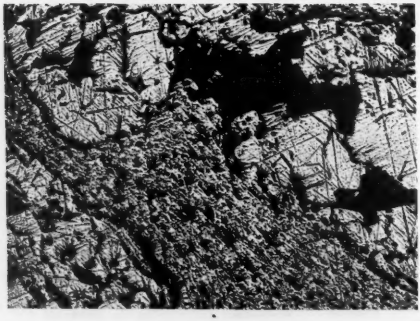

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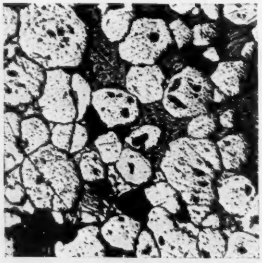

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a. Flinflon, Manitoba. Typical structure of ore. Pyrite white, sphalerite dark-gray. Polished section (×82).

b. Northpine Pyrite Mine, Ontario. Crushed pyrite. Light-gray is pyrite and black areas are gangue. Polished section (×25).

c. Eustis Mine, Quebec. Rounded grains with high relief are pyrite. Interstitial material, low relief is chalcopyrite (white) and sphalerite (gray). Gangue is black. Polished section (×15).

the sulphide zone, the rock is schistise and contains much sericite.

Thin sections of the more intensely altered wall rock contained only sericite, quartz, and pyrite. Apparently potassium and sulphur have been added in considerable quantity. There has also been some addition of silica and iron and a leaching of magnesium and calcium.

Genesis.—The large amount of pyrite, the presence of arsenopyrite and magnetite, and the absence of typical low temperature minerals, suggests that the ore was deposited under conditions of intermediate to high temperatures. The sericitization, silicification, and the impregnation of the wall rock with pyrite, show that the ore was introduced by solutions. It is believed that the ore was deposited by hydrothermal solutions ascending along the more schistose zones in the Amisk rocks. The data available do not prove the source of these solutions. It is assumed that there exist underlying granites at no great depth, from which the quartz porphyry dike is an apophysis, and that the solutions were given off by the magma during its solidification.

Conclusions.

Character of Rock at Time of Ore Deposition.—If the deposits had been formed in lenticular brecciated zones before the rocks were sheared, and if the later schistosity developed parallel to these lenses, it is apparent that the form of the ore bodies would be similar to those formed in schistose rocks. In the deposits examined, inclusions of schist were found in the ore with the schistosity parallel to that of the wall rocks. The inclusions were impregnated with pyrite and there was no evidence to show that the inclusions had been deformed after the deposition of the pyrite. If the deposits were formed before the rocks were sheared, rock inclusions would probably be impregnated with pyrite. Later deformation might convert the inclusions into schist, but here there would be evidence to show that deformation had taken place after the pyrite had been deposited. If the veins were deposited before the rocks were sheared, and later schistosity developed at an angle to the veins, they would not be rotated to a parallel position. They might be broken to form

small overlapping lenses[14] as in the Slocan district. Here the schistosity of the wall rocks would curve around the broken ends of the ore bodies. In places, the schistosity would strike at high angles to the general schistosity of the country rock, as at the Milan Mine.[15] In northern Manitoba, however, the ore bodies are found in sheared zones parallel to the strike of the schistosity of the country rock.

For the reasons given above, it is believed that the deposits were formed in schistose rocks and that the schistosity was parallel to that now present.

Size of Ore Body Determined by Extent of Shearing and Brecciation.—The general form of the larger deposits, lenticular masses with vein-like extensions at the ends where the rock is less schistose, suggests that the solutions entered along several fractures in a sheared zone. Where the rock was more thoroughly sheared it was more easily attacked by the solutions, with the result that the intervening bands of schist were completely replaced. Where several veinlets of sulphide make up the whole ore zone, as in the smaller mineral deposits of the district, the rock is only slightly schistose and has not been replaced nor impregnated with pyrite to any marked extent. It is concluded that the degree of schistosity of the country rock as well as the amount of material supplied in solution, has been of prime importance in determining the size of the deposits.

THE NORTHPINES PYRITE MINE, ONTARIO.

Location and Relief.

The Northpines pyrite mine is situated at the east end of Vermillion Lake, Ontario. The mine is 1½ miles south of Pelican, a station on the Canadian Government Railway about 240 miles east of Winnipeg, Man., and about 180 miles northwest of Ft. William, Ontario.

The relief features are typical of the Canadian Shield. Ridges of rock occasionally rise to elevations of 200 feet above the inter-

[14] Uglow, W. L., *op. cit.*, pp. 643–662.

[15] Emmons, W. H., U. S. Geol. Surv. Bull. 432, p. 62, 1910.

vening marshes and lakes. The ridges and depressions have an E. N. E. trend, and this is also the strike of the schistosity of the rocks. Glacial drift is fairly abundant, and sinuous esker-like ridges are not uncommon. The drainage is northward into Hudson Bay.

Geology.

General Geology.—The mine is situated in an east-west trending belt of Keewatin and Lower Huronian rocks. The belt is about 20 miles wide and about 200 miles long, and is in many places, pierced by stocks and interrupted by tongues of granite. It is completely enclosed by granite. The structural lines in these rocks follow the general trend of the belt, and are always approximately parallel to neighboring granite contacts.

The rocks of the area have been mapped as three units:

Laurentian
Intrusive Contact Zone
Keewatin and Lower Huronian.[16]

The Keewatin—Lower Huronian is an old igneous and sedimentary complex. The Contact Zone rocks consist of hornblende schists and amphibolites enclosed in gneiss. The Laurentian contains batholiths of granite, granodiorite, and gneiss. Glacial drift, made up chiefly of bowlder clay, forms a fairly heavy cover and in depressions in the immediate vicinity of the mine, is 8 to 20 feet in thickness. The age of the separate units has not been clearly differentiated. It is believed that the igneous complex is the oldest and that the sediments are older than the granite. Consequently, if the sediments are really Huronian, the granite would probably be of Algoman age.

For further information in regard to the region in general see the following publications.[17]

[16] Collins, W. H., "A Geological Reconnaissance of the Region Traversed by the National Transcontinental Railway Between Lake Nipigon and Clay Lake, Ontario," Geol. Surv., Can., No. 1059, pp. 20–45, 1909.

[17] Collins, W. H., Geol. Surv., Can. Guide Book No. 9, p. 155, 1913.

Collins, W. H., "A Geological . . . Clay Lake, Ontario," Geol. Surv., Can., No. 1059, 1909.

Moore, E. S., "Vermilion Lake Pyrite Deposits," Ont. Bur. of Mines, vol. 20, pt. 1, pp. 199–209, 1911.

Country Rock near the Mine.—Granite is exposed about 2½ miles northeast of the mine. Thin sections show abundant quartz, microcline, and orthoclase, some acid plagioclase and some biotite, titanite, apatite, magnetite, epidote, chlorite, and sericite. Biotite is rare and is partially altered to chlorite. Epidote is abundant but may be entirely secondary.

Moore states that the hanging wall (north wall) of the mine consists of basalt-breccia and green schist and says that there appears to be a narrow band of metamorphosed sandstone near the hanging wall.[18] The basalt-breccia consists of slate-like fragments cemented by calcite. The fragments are elliptical in section and are elongated parallel to the foliation of the rock. They consist of a dense mat of uralite fibers and contain also a little chlorite, epidote, zoisite, and granular quartz. The cement consists almost entirely of calcite, but there is also some quartz and pyrite present. Moore believes that the fragments are basaltic material, and that the cement was probably deposited by the ore solutions.[19]

On the footwall side of the deposit are masses of diabase. The diabase is sheared only in local areas, but is believed to be a part of the Keewatin complex. The rock is composed almost entirely of the secondary minerals uralite, chlorite, and epidote.

The Pyrite Deposit.

History of Development and Production.—The mine has been known at various times in the past as the Michie Mine, Northern Pyrite Mine, Vermilion Pyrite Mine, and the Northpines Mine. The deposits were discovered many years ago, but extensive development and mining have not been carried on until recently. The demand for sulphuric acid created by the World War stimulated its development. The mine has been developed to a depth of 500 feet, and at present, the ore is being taken chiefly from the 500-foot level.

[18] Moore, E. S., "Vermilion Lake Pyrite Deposits," Ont. Bur. of Mines, vol. 20, pt. 1, pp. 200–206, 1911.

[19] *Op. cit.*, pp. 202–204.

Production began in 1908, and in the years 1913–1917 exceeded 400,000 tons of ore.[19a]

General Character of Deposit.—The deposit is tabular in shape and follows the strike and dip of the enclosing rocks. The thickness varies from 10 to 70 feet. The length and depth are not known, but the ore body shows no diminution in size where it has been developed, that is 1,000 feet along the strike to a depth of 500 feet. The deposit strikes east-west and has an average dip of 60 degrees to the north.

The footwall of the ore body is well marked; practically pure pyrite rests against wall rock which is only slightly impregnated with pyrite. Slickensides and gouge are present in several places along the footwall. A zone a few feet wide along the hanging wall consists of bands of country rock and bands of sulphide. The curtains of schist contain a good deal of pyrite.

Occupying a medial position in the ore body is a lenticular quartz vein which contains some pyrite and shows gradational facies to pyrite ore. The quartz is finely granular.

The sulphides show a banded or streaky texture roughly paralleling the strike of the deposit. The bands consist of lenticular streaks of pyrite and quartz crystals, laminated with exceptionally fine-grained pyrite.

Mineralogy.—The hypogene metallic minerals present in the ore are pyrite, pyrrhotite, magnetite, chalcopyrite, and sphalerite. Supergene minerals present are limonite and melanterite. The gangue is made up of inclusions of schist and the minerals quartz and calcite.

Pyrite is by far the most abundant sulphide in the ore body. It has two general modes of occurrence; as coarsely crystallized bands and as extremely fine-grained crushed zones. The pyrite in the crushed zones forms a solid mass of minute granules, and there is an apparent flow structure around unbroken pyrite crystals.

Pyrrhotite is present as minute blebs included in pyrite and as irregular branching areas between pyrite grains. Most of the

[19a] Reports of the Ontario Bureau of Mines for the years 1909 to 1918.

pyrrhotite is found near the hanging wall as interstitial material between the pyrite grains. Magnetite is present in equidimensial grains which usually contain small inclusions of pyrite. Some of the magnetite grains have been fractured, but the mineral has not yielded to deformation as easily as pyrite. Sphalerite and chalcopyrite are extremely rare. They occur as minute blebs included in pyrite.

Moore mentions a massive sulphide in the ore lighter in color than the pyrite, which he says may be marcasite.[20] In the present investigation, it was seen that the finely crushed pyrite had a slightly different color in polished specimens from the well crystallized pyrite. Also, there could be distinguished two slightly different shades of color in the well crystallized iron sulphide. This may be due to different orientations in the crystals. In any case the presence of marcasite was not proved.

The most abundant gangue is included country rock, and even this is rare except in local places near the hanging wall. Quartz and calcite are present interstitial to the pyrite crystals, in the streaks of well-crystallized pyrite.

Among the metallic minerals pyrite was the first to crystallize. Magnetite appears to be later than the earliest pyrite, but it is probable that pyrite continued to be deposited after all of the magnetite had been formed. Pyrrhotite is clearly later than these two minerals.

Wall Rock Alteration.—Diabase forms the footwall in several places, but usually, the diabase is separated from the ore by a few feet of chlorite schists. There has been very little alteration along the footwall. The diabase may have been intruded after the deposition of the ore, and former alterations due to the ore solutions may have been obliterated, but this does not seem to be the case. The dense nature of the rock at the footwall was probably effective in preventing alteration.

The hanging wall consists of basalt-breccia, chlorite schist, and biotite schist. Most of the wall rock alteration has taken place along the hanging wall. From study of thin sections of

[20] *Op. cit.*, p. 206.

hanging wall rock, it is apparent that there has been much introduction of metallic minerals and quartz from the ore solutions and a development of sericite, carbonate, and biotite. Some of the schist along the hanging wall has apparently been derived from sedimentary rock and the biotite may be authigenous. However, the fact that biotite is present in small veinlets with quartz, calcite, and vermicular chlorite, suggests that it was developed in part by the ore solutions. Small reddish-brown crystals of garnet are present in some of the bands of schist included in the ore. The garnet occurs in very local aggregates and may have been developed by the or solutions. Fralcck notes the presence of tourmaline in the hanging wall rocks.[21]

The thin sections contain much evidence of deformation after the development of the ore and wall rock minerals. Garnet and quartz are crushed to some extent, and the soft chlorite curves around these hard minerals. Sulphides are often in elliptical areas arranged parallel to the foliation of the rock.

Structure of the Banded Ore.—The coarser grained seams consisting of pyrite and quartz are typically lenticular where the ore has been severely crushed and are usually about 1 mm. wide. Where crushing has been less intense, the coarser grained areas are more irregular and make up the greater part of the ore. The outside edges of the crystals in the seams have been rounded. In some places, individual crystals of pyrite have not been completely granulated and are found as small lens-shaped areas embedded in granular pyrite. Small druses, containing singly terminated crystals of quartz and cubes and pyritohedrons of pyrite, are not uncommon. They are confined to the uncrushed ore.

The finely-crushed pyrite shows a flow structure. Any particular band shows pinching and swelling and a curving around uncrushed grains of pyrite. This is particularly noticeable where uncrushed pyrite forms a large proportion of the ore (Plate XX, *b*). The individual grains in the crushed material are not

[21] Fraleck, E. L., "Iron Pyrites in Ontario," Ont. Bur. of Mines, pt. 1, p. 176, 1907.

distinct from one another but are cemented by pyrite, and this gives the ore a massive appearance. Polished specimens of the material, however, show a rough surface which is quite distinct from the relatively smooth surface on polished pyrite crystals.

Genesis.—The relation of the quartz vein to the sulphides is not clear. The small amount of quartz gangue in the ore crystallized later than the pyrite. This relation can be seen in the small druses and in many uncrushed areas where quartz is interstitial between pyrite crystals and fills small fractures in pyrite. All of the quartz and sulphides were probably formed during one definite period of ore deposition, but conclusive evidence was not obtained to show whether the quartz vein was formed early or late in this period.

The granular quartz of the quartz vein and the structures observed in the pyrite ore, strongly suggest intense regional metamorphism after the formation of the ore body. The temperature, as well as the pressure, was probably high at the time of this deformation, as the pyrite appears to have flowed after granulation.

Adams, using Kick's process for working at high pressures, produced granulation of pyrite but not flowage, at a pressure of 43,000 pounds per square inch and at ordinary temperatures.[22]

Emmons, referring particularly to the Milan Mine, states that much evidence of severe crushing is found along the edges of the deposit, but the interior of the mass of pyrite has remained intact. He states that pyrite is crushed and recemented and finally shows no trace of deformation.[23] At the Northpines Mine, however, the pyrite clearly shows evidence for granulation, recementing, and probably flowage. It seems probable that if any pyrite mass were subjected to differential pressure sufficient to crush the pyrite, the structures developed would not be obliterated through recementation, but the ore would show evidence proving that it had been crushed.

[22] Adams, F. D., "An Experimental Investigation . . . by Prof. Kick," *Jr. Geol.*, vol. 18, pp. 509–510, 1910.

[23] Emmons, W. H., "Some Ore Deposits in Maine and the Milan Mine, New Hampshire," U. S. G. S. Bull. 432, pp. 57–58, 1910.

It would appear that at the Northpines Mine, the ore originally occurred as coarsely crystallized as the present material in the seams of uncrushed pyrite. During regional metamorphism much of this material was crushed and probably squeezed out in curving lines around uncrushed material.

Fraleck believes that the deposit was formed in part by open space filling and in part by replacement.[24] Collins refers briefly to the deposit as occupying a well-defined fissure.[25] Moore favors the view that the deposit represents fissure filling.[26]

There appears to be no evidence favoring a replacement origin along the footwall. Along the hanging wall, however, the ore contains numerous inclusions of schist, orientated parallel to the strike of the country rock schist. This is held to be good evidence that near the hanging wall there has been much replacement of country rock. Some of the rocks of the hanging wall are apparently sedimentary and they contain considerable calcite. It is probable, that replacement has been active along the hanging wall, and that the rocks replaced were chiefly calcareous sediments.

The ore solutions were of such a nature that they were competent to deposit large masses of pyrite and much pyrrhotite and magnetite. Silica was abundant at a certain stage, and carbon dioxide was also present to a marked extent. The presence of the minerals pyrrhotite, magnetite, tourmaline, and biotite, shows that high temperatures and pressures prevailed during ore deposition.

The source of the material is not clear. Since small pyrite deposits are associated with granite dikes in the eastern part of the area, and because of a large amount of pyrite in the granite which is supposed to be the source of the pyrite at Sturgeon Lake, in the same mineral area, Moore concludes that the granite is the most probable source.[27]

The deposit has been subjected to severe regional metamorph-

[24] *Op. cit.*, pp. 176–177.
[25] *Op. cit.*, p. 61.
[26] *Op. cit.*, p. 208.
[27] *Op. cit.*, p. 208.

ism, however, and if this deformation is associated in time with the granite intrustion, it would seem probable that the deposit had been formed at some earlier time. A period of deformation probably occupies sufficient time for the formation and the later severe crushing of an ore body, but it is true in general, that ore deposits are not severely crushed when they are associated in origin with the latest batholithic intrusions of a region. It seems, however, that the most likely source is the granite.

THE EUSTIS MINE, QUEBEC.

Location and Topography.

The Eustis mine is one of the numerous pyrite-copper mines in the eastern townships of the Province of Quebec and is located at Eustis, on the Boston and Maine Railway, about 7 miles south of Sherbrooke.

The area was affected by the Appalachian Revolution and is characterized by ranges of hills trending northeast and southwest. The principal rivers transect these structural lines at right angles and flow northwest into the St. Lawrence River. The tributaries to the main streams flow parallel to the Appalachian folds. The main streams are then either antecedent or superimposed, and their tributaries are subsequent.

Geology.

General Geology of District.—The geology of the region is complex. The oldest rocks occur in three parallel ridges about 25 miles apart. These formations are schistose derivatives of acid, intermediate, and basic igneous rocks, believed to be of Pre-Cambrian age. It is in these belts of igneous rocks that most of the ore deposits of the Eastern Townships are found. The Eustis mine lies in the middle belt of the three, which is known as the Ascot or Stoke Mountain Belt. Outside of these three belts, the rocks are chiefly sedimentary and are of Pre-Cambrian, Cambrian, Cambro-Silurian, Silurian, and Devonian age.[28]

[28] Dresser, J. A., "Report on the Copper Deposits of the Eastern Townships of Quebec, with a Review of the Igneous Rocks of the District," Geol. Surv., Can., No. 974, pp. 17–26, 1907.

Besides the Pre-Cambrian igenous rocks there are also isolated stocks and dikes of basic to intermediate intrusive rocks ranging in age from early Cambrian to late Silurian or early Devonian, small granite batholiths of late Devonian age, and later Paleozoic dikes of camptonite, bostonite, and diabase. The Paleozoic igneous rocks, with the exception of the latest dikes, show, in general, a foliated structure. The sedimentary rocks are all sharply folded. The Pre-Cambrian rocks are severely sheared and metamorphosed. The structural lines in all of the foliated rocks have a northeast and southwest trend.

Geology at the Eustis Mine.—Bancroft believes that the rocks at the Eustis mine are sericite schists derived from quartz porphyry intrusions. He states that the less schistose facies display abundant phenocrysts of quartz, orthoclase, and plagioclase, in a groundmass which consist of smaller grains of these minerals, with a small amount of sericite, chlorite, carbonate, zircon, rutile, magnetite, and pyrite.[29]

Subsequent to the development of the ore bodies, the district has been traversed by faults, chiefly transverse to the strike of the schists. Several have been encountered in the Eustis mine, the largest having a throw of 60 feet. Alkaline dikes of late Devonian age cut the ore bodies and have no genetic relation to the ore deposits.[30]

Several dike-like bodies, parallel to the foliation, were seen in the sericite schist country rock. They are only slight-sheared and contain phenocrysts of quartz and albite, in a very fine-grainer groundmass consisting of the same minerals. Sericite was a common secondary mineral, and cubes of pyrite were not uncommon. It is probable that these rocks antedate ore deposition.

The Ore Bodies.

History of Development and Producion.—The Eustis ore deposits were discovered in 1865, and the mine has been operated

[29] Bancroft, J. A., "Report on the Copper Deposits of the Eastern Townships of the Province of Quebec," Dept. of Col., Mines, and Fish., Mines Branch, P. Q., Canada, p. 88, 1915.

[30] *Idem*, pp. 68–72.

practically continuously since 1879. In the early period of mining, copper, with a low content of gold and silver, were recovered. The mining of pyrite for sulphur apparently began in 1886. At present, the copper content in the ore is about 2 per cent., and the best pyrite ore contains about 45 per cent. sulphur. Mining has reached a depth of 4,000 feet along a 38-degree incline. Bancroft states that more than a million tons of ore have been shipped from the property.[31]

General Character of the Ore Bodies.—The ore deposits consist of several lenticular bodies of ore arranged en echelon and completely enclosed in a country rock of sericite schist. The individual ore bodies lie parallel to the foliation of the enclosing rocks; consequently, the general trend of the ore zone, composed of all the ore bodies, is not parallel to the foliation of the rocks. The deposits usually overlap along both the strike and dip, so that two or more deposits, separated by bands of schist, have been mined on the same level and for some distance along the strike.

Although the strike of the country rock is fairly constant, the dip varies considerably. In some places, the planes of schistosity are horizontal, and in other places, they are vertical. No relation has been noted between the location of the ore bodies and the frequent changes in dip in the rock. Where one ore body is present over several waves in the dip, it follows the schistosity, and only minor stringers of ore transect the foliation of the rock.

The walls of the ore deposits are not sharply defined, but there is a gradual transition from ore to country rock. Horses and continuous bands of schist are occasionally present. The ore is granular pyritic sulphide containing very little gangue material beyond some inclusions of country rock.

In the literature on the district, the ore bodies have been ascribed to deposition from meteoric waters which concentrated the metals from the surrounding rocks and deposited them in sheared zones.

Mineralogy.—The metallic minerals identified, are pyrite, chalcopyrite, sphalerite, bronite, tennantite, and galena. Pyrrhotite

[31] *Op. cit.*, p. 239.

and tetrahedrite have been recorded.[32] Gangue minerals are rare and consist of quartz, sericite, carbonates, and barite.

The order of crystallization is not definitely established. There has been considerable overlapping, but the general order from the earliest to the latest is quartz, sericite, and carbonates; pyrite; chalcopyrite, sphalerite, and bornite; tennantite; galena. Quartz and carbonates continued to some extent during ore deposition. Pyrite is clearly the earliest of the ore minerals. Chalcopyrite and sphalerite are in general earlier than tennantite and galena. Bornite was not present in sufficient quantity for absolute location in the series. Tennantite is in general earlier than galena but later than sphalerite.

Pyrite is abundant and is crystallized in cubes and pyritohedrons, which are, in many places, grown together to leave small irregular interstices which are filled with the other sulphides. The pyrite commonly contains small rounded inclusions of the other sulphides. In some places, the pyrite is present as polygonal grains embedded in a matrix consisting of the other sulphides (Plate XX, *c*).

Tetrahedrite[33] has been mentioned as one of the ore minerals. In the present investigation, the mineral resembling tetrahedrite proved to have the chemical composition of tennantite.

Alteration of Wall Rock.—The universal wall rock alteration is a pronounced impregnation with pyrite. The non-metallic minerals making up the wall rock are quartz, albite, and other acid plagioclase, sericite, carbonates, and rutile. These minerals are the ones that make up the normal country rock, consequently, it is difficult to determine to what extent they have been developed by the ore solutions. Quartz is apparently more abundant near the ore body than farther away. Carbonates have been introduced. A little sphalerite is present in the wall rocks. It is believed that the pyrite and sphalerite, nearly all of the carbonate, and some of the quartz and sericite have been formed in the wall rocks through the agency of the ore solutions. The mineral referred to as sericite, may be paragonite.

[32] Bancroft, J. A., *op. cit.*, p. 241.
[33] Bancroft, J. A., *op. cit.*, p. 241.

Closely associated with the ore are bands of what is locally called "green rock." Bancroft believes that "green rock" has resulted from alteration and partial replacement of schistose quartz porphyry by carbonate bearing waters.[34] "Green rock" contains carbonate, quartz, chlorite, sericite feldspar, rutile, and pyrite. Chlorite is abundant, and gives the rock its green color. Sericite is of minor importance. The characteristic mineral is a carbonate which in the literature has been referred to as dolomite. The writer is in accord with the theory, that this rock represents an alteration and replacement by carbonate solutions, but dolomite and chlorite, extremely rare in the normal wall rock of sericite schist, are common in the "green rock." It is concluded that "green rock" has resulted from alteration of a rock of intermediate composition in the sericite schist.

Genesis.—Dresser believes that the ore deposits were deposited in schistose rocks, and that the source of the metals is the rock, in which the ore bodies are found.[35]

Bancroft concludes that the ore deposits of the Eustis mine were formed through the agency of ascending waters. Since the large ore deposits of the district are mostly found in sericite schists, he concludes that the source of the metals was these schistose rocks.[36]

Paleozoic intrusive rocks are present in the region ranging in age from early Cambrian to late Devonian. It is not known whether or not they are genetically related to the ore deposits, but is has not been proved that the ore bodies are of Pre-Cambrian age. Numerous copper deposits in the area are found in Silurian and earlier Paleozoic rocks at the contact with diabases. Some of the typical pyritic deposits are found in Paleozoic rocks at the contacts with intrusive stocks of diabase. Such are the Garthby and other smaller deposits in the area.[37]

The Weedon and Stratford mines, which are typical pyritic

[34] *Op. cit.*, p. 241.
[35] *Op. cit.*, p. 12.
[36] *Op. cit.*, pp. 68–71, 242.
[37] Bancroft, J. A., *op. cit.*, pp. 190–194.
Dresser, J. A., *op. cit.*, pp. 12–15.

deposits consisting of pyrite and some pyrrhotite, chalcopyrite, and sphalerite, in a country rock of chlorite and sericite schists, are both located only a few hundred feet from the margin of a granite stock 15 square miles in extent. Bancroft gives good evidence, such as considerable impregnation with pyrite of the schists and Cambro-Silurian sediments near the contact, to show that the granite was the probable source of the ore. Some ore deposits in the same locality are found in both the chlorite-sericite schists and the Cambro-Silurian sediments. However, because granite has not been found associated with the other large ore deposits in sericite schists, and because a small dike of aplite has been found cutting the lower portion of the Weedon ore body, Bancroft concludes that the ore was formed before the granite was intruded. The Weedon and Stratford mines are very similar to the Eustis mine, but they contain more pyrrhotite, and hornblende is recorded as a gangue mineral in the Stratford mine.[38]

It seems more reasonable to regard the Paleozoic intrusive rocks of the region as the source from which the metals were derived. Further field and laboratory study is necessary, however, before the origin of the ore bodies can be firmly established.

GENERAL CONCLUSIONS.

Form of Individual Lenses.—Pyritic deposits in schistose rocks have all gradations in form from thick elliptical lenses to veins of constant width. Most of the deposits of this class have the form of elongated ellipsoids. Many are vein-like, but the vein shows frequent widening or narrowing, according as the enclosing rock is more or less schistose. Most of the individual lenses have a longer pitch-length than a strike-length.

Gold-quartz deposits in schistose rocks have a lenticular form when they lie parallel to the foliation of the enclosing rocks. In the Eastern and Southeastern States, numerous pegmatites and granites intrusive into schistose rocks, have a lenticular form. The shearing in any rock is not uniform, individual shear planes

[38] Bancroft, J. A., *op. cit.*, pp. 271–287.

are not continuous, local areas are intensely sheared and other areas are practically unsheared. This local shearing and consequent development of lenticular ore bodies, has been discussed lucidly by Graton.[39]

Replacement deposits in sedimentary rocks do occasionally have a rough lenticular form according as particular strata are more easily replaced, and the origin of the form of these deposits is in many ways analogous but not exactly similar to that of ore bodies included in schists. It is concluded that the form of pyritic deposits is determined by the nature of the enclosing rocks. If the rocks are schistose the ore bodies are lenticular.

In the pyritic deposits of northern Manitoba, in the Weedon, Stratford, Capelton, Eustis, and other mines in Quebec, in Huelva, Spain,[40] in Kyshtim, Russia,[41] and probably in many other deposits of this class, the lenses usually pinch out along the strike and in depth as a few parallel narrow veinlets. In the literature dealing with these deposits, the theory is expressed that the ore bodies had been formed after the rocks had been rendered schistose. The theory is also put forward, that the degree of schistosity has been of primal importance in determining the size of the ore bodies. Ore is found only in the more sheared zones, and the ore bodies pinch out where the rocks are less schistose.

The ore bodies lie parallel to the planes of schistosity and only minor irregularities, such as small veinlets, occasionally transect the direction of cleavage. In a few deposits, such as the Milan Mine, New Hampshire, and the ore bodies at Rammelsberg, Germany, the strike of the ore body is not always the same as that of the country rock. Here there has been deformation after the deposition of the ore. Pyritic deposits proved to have been greatly modified by post-ore deformation are rare, and in the

[39] Graton, L. C., "Gold and Tin Deposits of the Southern Appalachians," U. S. Geol. Surv. Bull. 293, pp. 35–37, 1906.

[40] Finlayson, A. M., "Pyritic Deposits of Huelva, Spain," Econ. Geol., vol. 5, p. 404, 1910.

[41] Stickney, A. W., "Pyritic Copper Deposits of Kyshtim, Russia," Econ. Geol., vol. 10, p. 601, 1915.

great majority of the deposits, the evidence to show that the ore was formed after the schistosity had been developed in the rock, is convincing.

The size of the individual lenses depends on the amount of material supplied in solution and on the space available for deposition. If the schistose rock enclosing the ore body is of uniform composition, one part will be as easily replaced as any other, and it is apparent that the degree of schistosity will determine the size. Where the rock is very schistose, the ore body is large. Where the rock is only slightly foliated, the ore bodies pinch out.

The Whole Ore Zone.—In many deposits, the whole ore body consists of only one lens or one lenticular vein of ore. In a good many deposits, the ore zone consists of several lenses of ore, usually arranged en echelon. Such is the case in Huelva, Spain; Kyshtim, Russia; Capelton, Stratton, Eustis, Weedon, in Quebec; and in many others. In rare instances, as at the Milan Mine, there are overlapping lenses of ore where the ore body has been broken off and there has been a displacement of the parts of one original ore body. Here the ore does not pinch out in parallel veinlets, and furthermore, the schistosity of the rock curves around the broken ends of the ore bodies. Post-ore metamorphism may cause an en echelon arrangment of the ore bodies, but this explanation will not apply to the great majority of pyritic deposits arranged in this manner. The schistosity of the enclosing rocks does not curve around the ends of the ore bodies, and the lenses pinch out in a series of parallel stringers. This shows that the ore bodies have not resulted from the breaking apart of one original lens.

Many pyritic deposits with an en echelon arrangement of the ore bodies are found at the contact between rocks which differ in competency. Many are found in schists which are apparently homogeneous. Stratified sediments, tuffs, and flows, and difference in grain in intrusive rocks, give zones or irregular areas of less competent material. If schistosity develops at an angle in strike or in dip, to any less competent zone, there will result a

zone of maximum shearing which is not parallel to the direction of the schistosity of the rocks. Individual lenses, arranged en echelon, are parallel to the planes of schistosity, and pinch out in less sheared material along the strike or dip. The whole ore zone, however, consisting of several lenses, is not parallel to the direction of foliation. It is believed that the en echelon arrangement is determined by zones of less competent material in the original rock which do not have the same strike and dip as the planes of schistosity which later developed. The body of each lens would lie in the less competent or more schistose zone, and the vein-like extensions would represent deposition in the more competent rock where schistosity was less pronounced.

Banded Structures.—Banding or parallel structures in general, present in many pyritic deposits, may in some instances be caused by post-ore metamorphism. This is apparently the explanation of the banding in the ore at Rammelsberg, Germany, and in the Northpines Mine, Ontario, This banding may have resulted from a flowage of some minerals or from a granulation along roughly parallel lines. It is not believed, however, that the banding present in all pyritic deposits which show this structure, has been formed in this manner. It is held that a banded ore may result from normal replacement of a schistose rock.

Stickney, in his work on Kyshtim, Russia, put forward the theory that the banded ore there resulted from replacement of sheared zones by solutions decreasing in iron content.[42] An analogous explanation has been offered for the banded ore at the Mandy Mine, Manitoba.[43] Finlayson emphasizes replacement of schistose rocks and differences in osmotic pressures of the sulphides as the probable cause of the banded ore at Huelva, Spain.[44]

Nature of the Solutions.—Pyritic deposits have been formed through the agency of solutions. The solutions were probably very concentrated in some deposits and dilute where broad zones

[42] *Op. cit.*, p. 601.

[43] Bruce, E. L., "The Amisk-Athapapuskow Lake District," Geol. Surv., Can., Mem. 105, pp. 71, 76, 1918.

[44] *Op. cit.*, p. 416.

of rock are slightly impregnated with sulphides. Gangue minerals are of scant quantity in these deposits, yet in the same mineral area there may be numerous gold-quartz deposits. It would seem that both types of deposit were derived from a single source through differentiation.

The deposits in Norway have been described as magmatic sulphide injections, and this seems to be the best explanation for the offset pyrrhotite deposits at Sudbury. Pegmatites and allied quartz veins in schistose rocks, are very irregular. They are held more and more to represent igneous injections, and the form should probably show some independence of the structure of the rocks in which they are found. There are indications that they were introduced under great pressure and actually tore apart the schists into which they were injected. The heavy sulphide deposits do not show this irregularity in form. They lie parallel to the foliation of the schists and there are not the same indications of injection under great pressure. It is believed that injected pyritic deposits are rare. Gangue minerals such as sericite, carbonates, chlorite, and barite, indicate more tenuous solutions.

Tolman and Rogers conclude that pyrite is rare in undoubted sulphide injections, and because of this and other reasons, they believe that there are no pyritic deposits formed as magmatic sulphide injections.[45] It is not believed that conclusive proof has been put forward for the exclusion of pyrite from magmatic sulphide minerals, but it would seem, that if there were any pyritic deposits injected as magmatic sulphides, some examples would be known in igneous rocks.

Source of the Material.—Nearly all pyritic deposits described in the literature, have been ascribed to solutions emanating from magmatic sources. Some have been ascribed to deposition from meteoric waters. In general, the absence of outcropping intrusive rocks in close proximity to the ore body in question, constitutes the argument in favor of a meteoric origin. The Strat-

[45] Tolman and Rogers, "A Study of the Magmatic Sulfid Ores," Stanford Univ. Pub., Univ. Series, pp. 65–66, 1916.

ford Mine in Quebec contains a good deal of pyrrhotite and also contains hornblende as a gangue mineral. In the literature, the theory is stated that here the ore was deposited from meteoric waters. The writer believes that enough has been learned concerning the conditions necessary for the formation of such minerals as pyrrhotite and hornblende to establish an igneous source for such deposits as those at the Stratford Mine.

In pyritic deposits there is a scarcity of gangue minerals. It is believed that if the ores were concentrated from the surrounding rocks, gangue minerals such as quartz and carbonates would be common. The metals have been concentrated as sulphides, and in some types of rock this would probably require an introduction of sulphur from some outside source. If meteoric waters were the ore bearing solutions, there would necessarily have to be considerable lateral movement of the solutions across the foliation of the rocks. It is believed that such movement of meteoric waters is insignificant. Pyritic deposits seem to fit in well in a medial position in the seven principal zones of ore deposition defined by Spurr, in which the metals are of igneous derivation.[46]

The writer believes that data concerning the source of the metals can be obtained from the order of crystallization of the minerals as well as from the type of mineralization. It would seem that meteoric waters obtaining their constituents from surrounding rocks would have a fairly constant composition, the proportions of the constituents varying according to their relative solubilities. Since pyritic deposits are found in foliated rocks which differ widely in composition, it is not believed that deposition from meteoric solutions would give the same definite sequence of mineral species throughout all of the deposits. Solutions from igneous sources vary in composition according to differentiation in the source, and this leads to a definite order of crystallization regardless of the composition of the rock in which the ore is deposited.

It would seem that a magma will give off different types of ore solutions at different stages in the differentiation of the magma,

[46] Spurr, J. E., "Theory of Ore Deposition," Econ. Geol., vol. 7, p. 489, 1912.

and that the ore deposits which result have a definite sequence. High temperature quartz veins and pyritic deposits are often found in the same mineral province. They do not appear to grade into each other and may be distinct differentiates from one source. Pyrite is the first sulphide to crystallize in pyritic deposits as well as in other sulphide deposits formed by hydrothermal solutions. Since pyritic deposits are composed essentially of pyrite, it would seem that they were formed at an earlier stage in the differentiation in the source, than that represented by chalcopyrite, sphalerite, tetrahedrite, deposits. The metallic elements present in pyritic deposits bear somewhat the same proportion to one another as they do in igneous rocks. Other sulphide deposits appear to represent a further differentiation in the source.

A probable reason why the lenses of sulphide in schistose are essentially pyritic is that these deposits are in general of replacement origin, and pyrite is the one sulphide which replaces any kind of rock with marked ease. The other sulphides do not readily replace siliceous rocks and are in general restricted to definite fractures.

GEOLOGICAL SURVEY OF CANADA,
OTTAWA, CANADA.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

CARBON RATIOS IN CARBONIFEROUS COALS OF OKLAHOMA, AND THEIR RELATION TO PETROLEUM.

Sir:—The recent contributions in the pages of your *Journal,* by Myron L. Fuller, to our knowledge of the relations between carbon ratios of coals and the occurrence of petroleum, with the equivol maps of North Texas[1] and Oklahoma[2] (also a map of northern Alabama[3] by Stewart J. Lloyd), should be welcomed by geologists, both for the assistance which they offer in the delimitation of our petroleum deposits and in the addition which they make to our knowledge of dynamic processes in these regions.

On the map of Oklahoma, the small number of analyses from which the isovols were drawn leads me to write a word of caution. The map prepared by David White[4] and the conclusions advanced by him were based chiefly on the Appalachian field where many hundreds of coal analyses were available. These analyses are from many different coal beds, about 50 minable seams being reported in West Virginia alone.[5] Errors due to

[1] Economic Geology, Vol. 14, No. 7, pp. 536–542, November, 1919.
[2] Economic Geology, Vol. 15, No. 3, pp. 225–235, April–May, 1920.
[3] Same, Vol. 15, No. 1, pp. 94–96, January–February, 1920.
[4] *Washington Acad. Sci. Jour.,* Vol. 5, No. 6, pp. 189–212, March 19, 1915.
[5] County Reports of the West Virginia Geological Survey.

variations in the analyses, noted by both Fuller and Lloyd—such as: Differences in fixed carbon content between weathered and unweathered samples, variations arising from the method of the analyst, variations due to original differences in the composition of the coals, and downward increase in fixed carbon percentages, —are readily apparent when sufficient data are available and can be eliminated or disregarded in the summation of results. Where, however, as in the Mid-Continent fields, relatively only a few coal analyses are available, the results obtained, though valuable and significant, cannot be regarded as possessing as high a degree of authority. Where in certain large areas no analyses are available, while in adjacent areas they are closely grouped, it is not unlikely that if more data were available much smoother curves (isovols) would be drawn; hence the necessity for a caution in drawing far-reaching conclusions as to the dynamic history of the region or the connection between irregularities in the isovols and structural conditions in buried series of strata.

It should be noted that the "lines drawn through the points of equal fixed carbon (or volatile matter)" were termed *isovols* by White,[6] and not "isovolves," as written in the recent articles on this subject, and also that Doctor White's paper appeared in *Volume 5*, not Volume 6, of the *Journal of the Washington Academy of Sciences.*

W. Armstrong Price.

West Virginia Geological Survey.

[6] White, David, *op. cit.*, p. 198.

REVIEWS

The Geology of the Mid-Continental Oil Fields. By Dr. T. O. Bosworth. 314 pages, one large map, 32 plates and text figures. New York, The Macmillan Company. Price $3.00.

In this book Dr. Bosworth has endeavored to present the most important geological facts relating to the occurrence of petroleum in the Mid-Contient oil fields. He has not attempted to draw many conclusions from the facts which he presents, believing that "so many circumstances yet remain obscure that the greater need is for the true presentation and analysis of facts," but has made an effort to effect a compilation of data that will permit an understanding of the more basic and fundamental conditions obtaining in the various districts, and to give a key to the location, history, and production of the more important pools.

The book is made up of 12 parts, each containing from one to 22 chapters of an average length of between 5 and 6 pages, sparingly illustrated by some 32 plates and figures, and at the back has a very complete index of 32 pages.

Part I. is composed of a short introduction and a bibliography of 42 references which are frankly only "some of the more important works relating to the region."

In Part II. by a very condensed account of the geographical and geological situation of the Mid-Continent oil region in which the Mid-Continent region is loosely defined as "including all the oil fields of Kansas and Oklahoma together with nearly all those of the northern part of Texas."

In Part III. the history of the fields is discussed in cycles of years rather than by districts. The cycles are apparently determined by the date of new discoveries of importance. Thus the period from 1903–1905 forms one division. The next cycle was inaugurated with the discovery of the Glen Pool in 1906, and continued until 1912 when the Cushing pool was opened. 1912–1915 is discussed as a unit, but the discovery of the Augusta-Eldorado pools of Kansas seemed justification for another division, covering 1916–1917. Succeeding this is 1918 marked by the opening of the north central Texas fields. The final period—1919—was apparently given a place by itself because of the ample data available relating to development. Following the discussion

of the cycles of development is a short statement regarding the lives of the fields and comments on probable future development.

In Part IV. the general structure of the region is dealt with. The oil fields are described as lying in a gentle monocline which dips northwestward and is bounded on east and southeast by the uplifted masses of the Ozarks and the Ouachitas. The Llamo-Burnet uplift of Texas, the Bend Arch, the Red River uplift, the Wichita-Arbuckle-Ouachita uplift, and the Namaha Mountains of Kansas, all of which lie on the edges or within the oil field region, are briefly described and their approximate locations shown by maps and cross sections.

The geological history of the region and oilbearing deposits are sketched in Part V. As Dr. Bosworth limits the oil-bearing formations to the Carboniferous, the history naturally begins with Mississippian time during which he postulates deposition in "an ancient Pacific Ocean" which "stretched across the present American continent from the Yukon to Florida." During the Mississippian, uplift began in restricted localities, but the great mass of the sediments were but slightly affected. Following Mississippian time there was a period of erosion, and then the Pennsylvanian beds were laid down in a shallow sea. The marine Permian he believes to have been deposited in almost land-locked remnants of the old sea, in waters whose concentration brought about beds of gypsum and salt. Upon these marine beds, non-marine accumulations were piled, forming the "red-beds."

The stratigraphy of the oil fields is given in Part VI. The Archean and Lower Paleozoic rocks are dismissed quite summarily with a short statement of where they outcrop, a little about their general character, and the names of some of the formations. No mention is made of their possibilities or impossibilities from an oil-producing standpoint beyond a statement that tarry deposits and asphaltum occur in them in the Arbuckle-Wichita region.

The beds of Carboniferous age are given much more elaborate treatment. For example the Mississippian is subdivided into the Mississippian of Kansas, of northeast Oklahoma, of southeast and southern Oklahoma, and of north Texas. Under each heading the author gives a short description of the beds to which he ascribes Missippian age, and also briefly discusses the oil fields which he thinks produce from rocks of Mississippian age, mentioning the county in which the field lies, the depth to the oil, initial productions, gravity of the oil, and other pertinent data. The same treatment is accorded the rocks to which Pennsylvanian and Permian ages are assigned.

Part VII. deals with the oil accumulations and their relation to geological structure. It begins with some general statements about surface

indications, oil sands, oil pools and their causes, the methods used in mapping structure, and the meaning of structure maps. Following this are descriptions of the structure in some twenty fields or districts of the Mid-Continent region. In the more elaborate of these descriptions the location, outline, and cross section of the anticlinal folds are given. Mention is made of the relation of production to the axis of the fold, and the relations to each other and to folding of oil, gas, and water. The apparent relations of productivity and structure are touched on in one or two instances and sometimes digressions are made to introduce details of history or stratigraphy. However, most of the descriptions confine themselves to brief mention of the outline and shape of the structure, the limits of production in comparison with the closure of the fold, depths to the principal producing sands, and initial productions. Part VII. terminates with a summary statement regarding the applicability of the anticlinal theory and a tabulation of fields believed to lie on domes and anticlines, on terraces, and those whose formation is apparently not due to either of the above mentioned structural features.

The character of the oil is dealt with in Part VIII. principally by tabulations of analyses and of specific properties of the oil, and the general conclusions that specific gravity values do not follow any particular geographical distribution, that the oil in the Permian red beds is heavier than in the other divisions of the Carboniferous, and that the specific gravity of the oil bears some relation to depth are drawn.

Part IX. discusses natural gas—the quantity produced, its geographical distribution, elations between gas and oil, exhaustion of the gas fields, and the chemical character of the natural gas. Special mention is also made of the helium content of some of the Mid-Continent gases.

In Part X. the author abandons geology for technology and discusses the percentage of gasoline in gas, briefly outlines the methods of extracting the gasoline through the compression and absorption processes, and gives some statistics for production of casinghead gasoline.

The salinity of oil field waters is dealt with in Part XI. This discussion is limited to the Mid-Continent field and gives some of the results of analyses of waters in the Augusta, Eldorado, and Blackwell districts.

The final division is devoted to general conclusions regarding the origin of the oil, relations between shore lines and the oil fields, migration of the oil and gas, relations between gas pressure and depth, and applicability of the theory of David White concerning the connection between geo-dynamic alteration of the sediments and their oil content.

This book deserves commendation because it is the first effort to compile some of the more important published descriptions of the Mid-

Continent oil and gas fields. Such a compilation is greatly needed. At present it is difficult to obtain a comprehensive knowledge of the conditions in the Mid-Continent fields unless one has access to an extensive library of geological and technical literature. The most detailed descriptions of the stratigraphy and almost all descriptions and portrayals of the structure are in reports published by the Federal and State geological surveys which are out of print and almost unobtainable. Articles of great importance are scattered through the files of trade journals and technical magazines. Some of the most illuminating information can be found only in general works on the petroleum industry of the United States. An effort to present in condensed form the most important of these scattered facts is indeed highly laudable and the author deserves credit for recognizing this need and endeavoring to fill it.

A compilation of published knowledge on the geology of the Mid-Continent region should cover the physiography, stratigraphy, structure, and geologic history, as all of these are related in some ways to the oil pools. It should discuss the origin, migration, and accumulation of oil, particularly as applied to the Mid-Continent region. Geologic field methods more or less peculiar to the Mid-Continent could profitably be included. Quality of oil and gas, the significance of the different types of waters that are found in the oil fields, life of fields, and estimates of production deserve a place in a work of this kind.

The statements of facts should be accurate, careful distinction should be made between known facts and unestablished theories, and there should be abundant references and a voluminous bibliography to enable the reader to check the information given to pursue investigations beyond the limits of the book. To be truly effective the work should be profusely illustrated, particularly in the section or sections dealing with structure, for it is impossible to present adequately the structural details of an oil field by means of a written description.

"The Geology of the Mid-Continent Field" abounds with inaccuracies and misstatements. It impresses the reviewer as being a hasty compilation of unweighed data from only a portion of the available literature on the Mid-Continent field. It shows either inexperience or carelessness in assembling, considering, and checking the material, and many contradictions are evidence of indifferent care in going over the data presented. Possibilities, unestablished theories, and deductions are in some instances presented without qualification as conditions that actually exist.

The errors, both of omission and commission, begin on the frontispiece, page 1, a general map of the Mid-Continent oil field. A large

black blotch indicates an extensive oil pool in McCurtain County in the southeastern corner of Oklahoma where actually the only indication of oil thus far found is some asphalt. In contrast to the addition of this non-existent field a number of small fields are omitted. As the map is drawn to a small scale, this is quite excusable in many instances where the fields would appear as insignificant dots near the much more conspicuous blotches that represent large producing areas. However, such significant developments as the small field east of Cushing and north of Bristow, the little Barnes field between Billings and Garber, the small pool at Holdenville in Hughes County, and the field at Cement in Caddo County, Oklahoma, and the Avis field in northeastern Jack County, Texas, should be shown.

Like the omission and inaccuracies on the map many of the errata are doubtless due to carelessness. Thus, on page 8, the author mentions the oil fields of Missouri separated from the Mid-Continent field by the Ozark uplift, when he probably has in mind the fields of western Illinois. The statement on page 16 that late in 1915 the Healdton field was yielding 90,000 barrels a day could be nothing but an error in copying, for this figure has not been given in any statistical report of the field's output. Errors of this type are harmless to the man who is fairly well versed in the petroleum geology and history of development in the Mid-Continent region, but become serious when they are seen and accepted by uniformed readers.

The contradictions are not so serious, although they detract greatly from the value of the book. In some instances the principle of majority rule can be applied. For example on page 147 Healdton oil is said to range in gravity from 42.7 to 27° Baume. At the same place the gravity is given as .8105 to .8383, which would make the range from 42.7 to 37° Baume. On page 209 the gravity of Healdton oil is given as 29.37 to 33.93 Baume. By turning to page 31 where there is a tabulation of the oils from different fields, confirmation of the last figure is obtained. Similarly on page 220 the author says the Strawn field is on a small "nose" but on both page 137 and page 223 the statement is made that it is on a small dome. On page 132 the deep oil of the Electra and Burkburnett region is credited to the Cisco formation, but on pages 134, 135, and 139 it is ascribed to the Canyon formation.

Still more serious are repeated misstatements concerning stratigraphy, structure, and production. One of the most glaring of these is the consistent reference to the Bend formation of Texas as Mississippian, in contradiction to the findings of Girty, Moore, Udden, Plummer, and Roundy, who have made careful determinations of the fauna, showing that unauthoritative statements in trade journals have been accepted

without attempt at confirmation from those who may be regarded as authorities. The statement on page 132 that there are Permian strata in the western part of Okmulgee County is refuted by the geological boundaries shown on the frontispiece. Similarly, if, as the author states, the deep production of the Yale field comes from the Mississippian, the map on page 53 showing the attitude of the Mississippian in Oklahoma must be in error. The assertion on page 141 that the red Permian beds are productive only in southern Oklahoma and northern Texas disregards the Garber field where the Hoy sand, high above the base of the Permian, has given notable production.

A serious shortcoming of the book is the paucity of references. A meager bibliography of 42 references and an occasional mention of the source of information does not furnish the aid to investigation that a work of this type should. The lack of confidence that results from the author's errors in statement makes this absence of adequate references particularly lamentable. Such references as are given are frequently incomplete.

The illustrations are also a point of weakness. Many points that could be made clearer by simple figures or diagrams have been left unillustrated. Some of the illustrations have been adapted from other publications without taking into consideration the effect of a necessary reduction in scale. The result has been to make the figures and words on some of these illustrations so small that they approach illegibility.

The arrangement of the book makes it unsatisfactory as a reference work. To obtain the data relating to any one field it is necessary to consult two, three, or four distinct sections of the book. Two sections on structure are separated by discussions of geological history of the oil bearing deposits and of stratigraphy in the oil field. There is a good deal of repetition which in many instances saves the reader the necessity of turning to another section of the book and although there are cross references these are incomplete, as they do not give the page number but only the part, section, and chapter.

The faults mentioned prevent this book from having much value as a handbook for the field geologist or a textbook for the student. The volume, however, does present in concise form many of the fundamental facts relating to the oil production in the Mid-Continent region and is therefore useful to any one unacquainted with the region who wishes to get a general idea of its history and of conditions obtaining there.

K. C. Heald.

Microscopic Examination of Ore Minerals. By W. MYRON DAVY AND C. MASON FARNHAM. 154 pages, New York, McGraw-Hill Book Co. 1920.

As applied in this case microscopical examinations are confined to observations by vertically incident light on clean or chemically treated polished surfaces. The ore minerals considered are, with the exception of about a score, too opaque to be studied advantageously by the more adequate methods in which transmitted light is used.

Definite directions are given for polishing, photographing and testing specimens. A determinative table of the minerals has been prepared on the basis of a few chemical reactions and of hardness tests on polished surfaces. Color and tenacity receive secondary consideration. The desirability of supplementing the microscopical examinations with certain physical tests and with blowpipe and other chemical tests is emphasized, and a chapter is devoted to such tests. "The microchemical reactions listed are from various sources. The authors have independently studied one hundred and forty-three mineral species . . .; and as most of these species are also listed in Dr. Murdock's book, it is believed that this triple check results in the accurate determination of the reactions."

One test depending primarily upon electrical conductivity is described so inadequately as to be of scarcely more than suggestive value. An erroneous conclusion might be drawn in Table 10 that covellite and magnetite have as great electrical conductivity as copper, whereas this table indicates only that one set of minerals (column 1) under the conditions named on pages 8 and 123 introduce resistances of less than about 2 ohms (that is, small in comparison with the resistance of the voltmeter); another set (column 3) introduce many thousand ohms; and a third set (column 2) introduce resistances of an intermediate range. The voltmeter readings of column 2 could not in general be reproduced under conditions which other observers could set up.

Sectile, a mineralogical term of rather definite meaning and application, is here used repeatedly in a different sense to describe certain effects produced by gouging a polished surface with a needle. By this test bornite and copper are "sectile" and chalcocite is "very sectile." A new term is needed, and such expressions as "sectile, but slightly brittle," as applied to galena, should be defined.

For bornite the ill-chosen color term "pinkish brown" has survived. Turgite is not sufficiently characterized with respect to color, streak, and structure and the formula given is open to question. The cleavage of chalmersite should be mentioned. Wurtzite does not have the cleavage of sphalerite and neither gives a really yellow powder. The usual

color of limonite by internal reflection is orange brown rather than reddish brown.

The formulas for calaverite, krennerite and sylvanite do not appear to correspond to the analyses; the following seem to be more nearly correct: calaverite and krennerite $(Au, Ag)Te_2$, sylvanite $AuAgTe_4$.

H. E. MERWIN.

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTE,
WASHINGTON, D. C.

SCIENTIFIC NOTES AND NEWS[1]

L. C. GRATON, geologist to the Calumet and Hecla Mining Co., is in Cambridge, Mass., temporarily. His present address is: Oxford Street, Cambridge, Mass.

FRANCIS B. LANEY, previously of the U. S. Geological Survey, has been appointed professor of geology in the University of Idaho School of Mines.

ALFRED H. BROOKS has recently returned to Washington from Alaska, where he has been investigating copper and oil deposits of the coastal region.

R. S. KNAPPEN has resigned from the faculty of the University of Chicago and is now teaching economic geology at the University of Kansas and devoting a part of his time to work in petroleum.

ALFRED W. STICKNEY, American mining geologist, has been captured by the Bolsheviki and imprisoned in Moscow.

HORACE V. WINCHELL recently returned from a professional trip to Alaska and has gone to Arizona.

E. S. MOORE, of the School of Mines, Pennsylvania State College, is pursuing the study of the refractories of Pennsylvania for the Pennsylvania Topographic and Geologic Survey Bureau and spent the past field season largely on the ganister deposits of the State.

R. M. OVERBECK, of the U. S. Geological Survey, returned from South America during the summer.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

SCOTT TURNER has been in The Pas district of northern Manitoba.

C. W. COOKE, of the U. S. Geological Survey, has returned from Colombia.

ADOLPH KNOPF has taken up his permanent duties in the Department of Petrology, Yale University.

HOWLAND BANCROFT has accepted the appointment of manager for the Sinclair Panama Oil Corporation and sailed for Panama in September.

C. W. PURINGTON, mining engineer, left Hakodate, Japan, for an examination of the coal fields of northern Sakhalin.

HERBERT E. GREGORY has returned to Yale University from the Hawaiian Islands.

K. C. HEALD, of the U. S. Geological Survey, in September made brief visits to a number of Survey parties working in the oil fields of Montana and Wyoming.

JAMES F. KEMP has been engaged in geological work in Utah during the summer and has now again taken up his duties at Columbia University.

W. P. WOODRING has been in Haiti, where he took charge of a U. S. Geological Survey party, making geological examination of the mountainous area of that republic.

T. A. BENDRAT, of Dryden, Mich., has been appointed head of the department of geology and oil geology at Phillips University, Enid, Oklahoma.

H. G. JENISON, of the U. S. Geological Survey, has been in San Francisco to investigate the copper-mining industry of the Pacific Coast.

HENRY LEIGHTON, professor of economic geology at the University of Pittsburg, has returned to Pittsburg after a summer spent largely in the examination of pyrite and iron ore deposits in the Algoma district, Ontario, Canada.

ROBERT D. LONGYEAR, geologist for the E. J. Longyear Co., has completed a geological examination for the Yellow Pine Mining Co. at Goodsprings, Nevada.

HAROLD YATES has been appointed lecturer in geology, mineralogy, and petrology in the Ballarat School of Mines.

S. F. SHAW has resigned as superintendent of the American Smelting and Refining Co. at Charcas, S. L. P. Mexico, to accept a position as manager of the Cia. Mra. La Constancia, at Sierra Mojada, Coahuila, Mexico.

HENRY KRUMB is now in Salt Lake City, after a visit to New York.

R. B. NIEDING, formerly manager for the Carbon Hill Coal Co., at Carbondale, Washington, is now manager for the Kennecott Copper Corporation at Kennecott, Alaska.

R. E. DAVIS has resigned as director of the Wisconsin Mining School, Plattsville, Wis., to engage in private practice.

WARREN R. ROBERTS, chairman of the coal section of the standardization committee of American Mining Congress, recently visited western Canada.

LESTER E. GRANT is now manager of the Braden Copper Co., succeeding S. S. Sorensen, who has gone to the New York office in a consulting capacity.

SIDNEY PAIGE returned to Washington October 4th, after studying the Homestake mine, South Dakota.

FRED P. SHAYES is now resident geologist with the Roxana Petroleum Corporation, in Covington, Okla.

C. M. WELD has removed his offices to 2 Rector Street, New York City.

T. H. O'BRIEN is general manager of the Inspiration Consolidated Copper Co., at Inspiration, Arizona.

JAY LONERGAN, mining engineer, has established permanent headquarters at 238 N. Wenatchee Avenue, Wenatchee, Wash.

J. ELMER THOMAS has opened an office for work as consulting geologist, at 751 First National Bank Building, Chicago, Illinois.